# ASTRONOMY®

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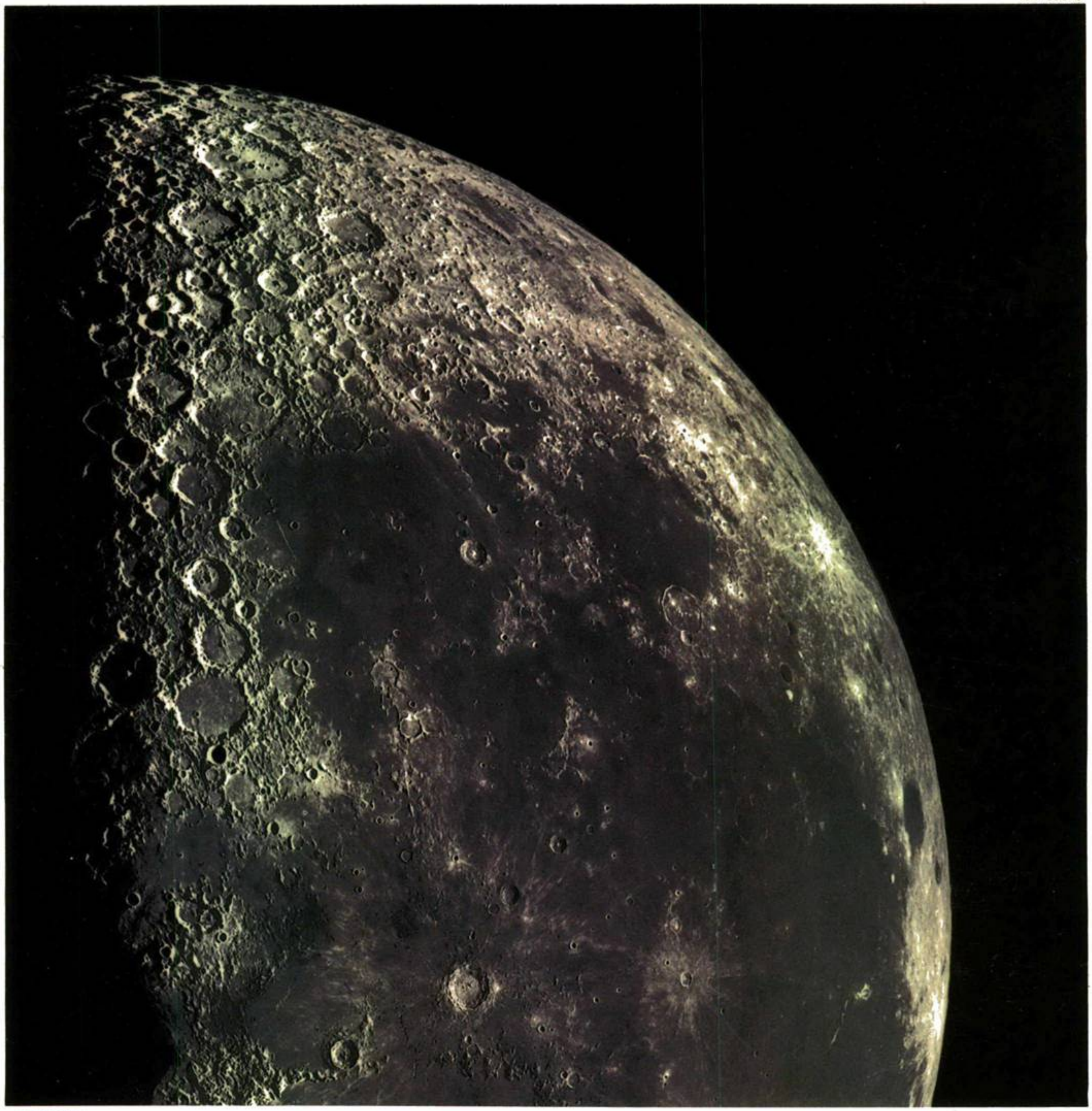

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**Explore the Moon's Wonders**

# Meade® Wide-Field f/6.3 SCT's:

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RA 23:58
DEC -35.6
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Focus
Near
2X
8X
Map
Quartz
Manual
Solar
Sidereal
Lunar
Reticle Adjust
U.S.A.
MEADE
MICROPROCESSOR CONTROLLED
LX QUARTZ PULSE DRIVE
Current (mA x 1000)
Dec Motor
Electric Focus
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Command Center
Power 12V.D.C.
C.A.T.
Encoders
N
S
On
Off

# The LX6 Revolution Is Here.

## For the First Time Ever — Wide-Field Schmidt-Cassegrain Telescopes that Yield a 60% Reduction in Photo Exposure Times!

**Meade 8″ Model 2080/LX6**

New Meade 8″ and 10″ LX6 Wide-Field Schmidt-Cassegrains combine the wide fields of view, fast photo exposure times, and high-contrast imaging long sought by the serious amateur. Consider this listing of *standard* LX6 features:

**1 Fast f/6.3 Schmidt-Cassegrain Optics —** *Optics that yield photographic and visual performance impossible to achieve with the f/10 optics that are standard on all other SC telescopes. Eyepiece for eyepiece, obtain:*

☐ A field of view that is **59%** wider than with f/10 Schmidt-Cassegrains. Use the Meade Super Wide Angle 40mm eyepiece on the 8″ LX6 to obtain a true field over *2 degrees* in diameter!

☐ Images both visually and photographically that are **2 ½ times** brighter than with an f/10 system.

☐ A **60%** reduction in astrophoto exposure times: 30 minute exposures become 12 minute exposures. Used with modern fast films, a **5-minute** color exposure of the Orion Nebula (M42) taken with the 10″ Model 2120/LX6 *yields virtually all of the nebular detail that is theoretically possible to obtain with a 10″ telescope!* With the optional Meade **Telecompressor Lens**, for an effective focal ratio of f/3.15, this exposure time is reduced still further to about **3 minutes** — an unheard of exposure time for a photovisual telescope of 10″ aperture, an exposure time that means *anyone* with an absolute minimum of experience can take magnificent deep-space astrophotos!

**2 Ultra High Contrast Baffling —** In addition to their superlative wide-field deep-space performance, Meade 8″ and 10″ LX6 models, because of their computer-optimized internal light baffles, yield uncompromised, high-contrast lunar and planetary images. Add the Meade 3-element **#140 2X Telenegative Barlow Lens** to obtain high-power lunar and planetary images at f/12.6.

**3 Built-In Digital Readout Capability —** One of the most important optional features ever made available on a Schmidt-Cassegrain: now you can find faint objects in seconds, not minutes. The LX6 Digital Readouts, located on the hand controller display, permit continuous monitoring of: *(a) telescope position in RA and Dec; (b) Local Time; (c) Sidereal Time; (d) a Digital Timer for photo exposures; and (e) Frequency readout of the pulse motor's input current* — a feature that enables extremely precise digital settings of the telescope's drive rate, readable to within ±.01 Hz. The observer simply depresses the "Mode" button on the hand controller to read out the listed data sequentially.

The Digital Readout package can be internally added easily and rapidly to the hand controller of your LX6, either at the time of purchase or at any future date, and is available at only modest additional cost.

**4 New Multi-Function Electronic Command Center —** The ECC hand controller, included as standard equipment, puts virtually every telescope function at your fingertips:

☐ *2X Drive Correction Speed* for precise electronic corrections during astrophotography.

☐ *8X Scanning Speed* for rapid electronic centering of the image in the field, or for roving about a specific sky region at 8 times the sidereal speed. Add the optional Declination motor for full dual-axis capability at 2X or 8X speeds.

☐ *Optional Digital Readouts*, described above.

☐ *Plus 6 other functions* that make Meade LX6's the only state-of-the-art Schmidt-Cassegrains available.

**5 Quartz Microprocessor-Controlled Electronic and Drive Systems —** The heart of every LX6 electronic system is a dedicated microprocessor that continuously controls, with quartz precision, all important electronic operations of the telescope, from the drive-rate frequency input to the main RA pulse motor, to the Electronic Command Center's multi-function digital readouts.

Augmented by the microprocessor, the RA pulse motor and LX worm gear system achieve true sidereal-rate tracking within ±.005% of the sidereal frequency, and with greater reliability than ever before. Switch to the "Manual" mode for variable Solar, Lunar, or Planetary tracking rates.

**6 Advanced-Design Power Panel —** Virtually every modern electronic accessory you might wish to add to your LX6 can be plugged-in directly to the telescope's power panel — accessories including the Meade **CAT Computer Aided Telescope** system *(see our other ad in this issue)*, with its library of more than 8000 astronomical objects; **Digital Readouts**, readable on the LX6 hand controller *(see above)*; **#1200A Electric Focuser**, for ultraprecise microfocusing; **12mm Illuminated Reticle Eyepiece**, for guiding during astrophotography; and the **Declination Motor**, for 2X/8X dual-axis operation.

In addition, the LX6 power panel includes an **Ammeter**, which continuously displays electric current usage, to gauge battery life during power cell operation; a **North-South Switch**, permitting your LX6 to be used anywhere in the world — simply flip the N-S switch to reverse drive direction for use in the Southern hemisphere; and **12-volts DC Power Inlet**. Each LX6 includes power cords for *3 types* of field operation: Directly from auto cigarette lighter plugs; directly from 115v. AC home outlets; and from the Battery Pack, included, using AA-size batteries supplied by the user.

**7 Plus all of the features you expect on a top-of-the-line Meade Schmidt-Cassegrain** — *Standard* features that include a **Super Plössl 26mm eyepiece** for exquisite definition and resolution across the entire visual field; 1/10-wave flat, multi-coated **2″ Diagonal Mirror** with eyepiece holders for both 1¼″ and 2″ eyepieces; **9 x 60mm Polar Illuminated Viewfinder**, the largest finder available on a commercial SCT; **Multi-Coated Optics Group**, with multi coatings on all lens and mirror surfaces for maximum light transmission and image brightness; **Equatorial Wedge**, with magnetic compass, latitude scale, bubble level, and micrometric azimuth control; and **Variable-Height Field Tripod**, the most stable in the industry.

**Priced only slightly higher than conventional f/10 Schmidt-Cassegrains, Meade 8″ and 10″ LX6 models achieve photographic and visual performance levels unobtainable with any competing telescopes.**

**Call or visit your Meade dealer now for further details and prompt delivery of the Meade 8″ Model 2080/LX6 or 10″ Model 2120/LX6 — from the World's leading manufacturer of Schmidt-Cassegrain telescopes.**

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**Bulletin LX6 —** Available at no charge, includes complete technical specifications, descriptions, and applications, with astrophotos, of Meade LX6 models.

**Complete Catalog Package #88C — $3.00 —** Includes catalogs and bulletins on the entire range of Meade astronomical telescopes, Series 4000 eyepieces, and accessories.

**Dealer Locations and Assistance —** For your nearest Meade dealer location, or for free telescope information and assistance, call Meade Instruments toll-free from anywhere in the continental U.S.A. (except California): **1-800-854-7485.** From all other areas, including California, call direct (714) 556-2291.

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**Meade Instruments Corporation**
*World's Leading Manufacturer of Astronomical Telescopes for the Serious Amateur*
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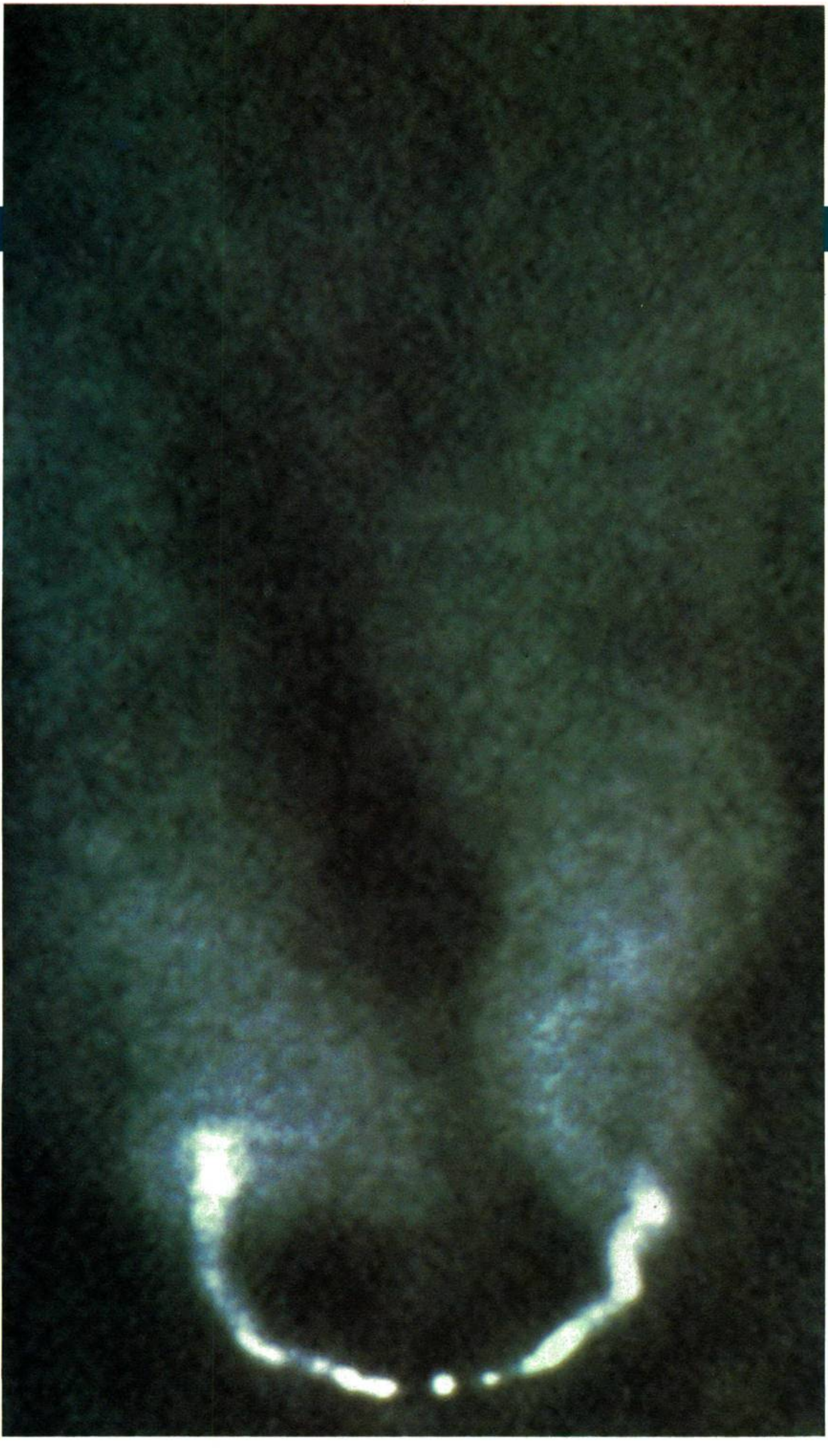
**ON THE COVER:**
Looked at the Moon lately? Fascinating geological oddities nestle among its craters and seas. Michael Kitt tells you how to find them. (See page 66.)



**BLOWING IN THE WIND,** two jets trail back from the radio galaxy NGC 1265 as it moves through the dense intergalactic medium. Jets are also bent by other forces. (See page 40.)

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## Behind the Scenes

# IN TOUCH WITH ASTRONOMY

The enormous hand fluttered over the ocher Martian landscape and then gently glided down the length of Valles Marineris. As one gargantuan finger nearly grazed the summit of Olympus Mons, the other fingers fluffed the clouds on the downwind side of the mighty volcano. As a smile spead across the mammoth face poised thousands of scale miles above the rocky landscape of Mars, a finger contacted the surface. Touchdown!

I had landed on Mars.

Astronomy is normally a science of seeing, a science of one sense only. Virtually everything we know about the worlds that orbit our Sun and everything we know about distant stars and galaxies have reached us through the sense of sight. We can't hear the Moon, we don't taste Venus, and there is no way to smell Mars.

But we can touch the Moon.

This month I asked associate editor Jeff Kanipe to build a model as part of his job in preparing the article by Ferdinand Miller, Jr., "Your Own Piece of the Solar System," for publication. Jeff is new to modeling planets and was rather reluctant to try, but he left his keyboard and crafted the fine Moon model you see in this issue. The story begins on page 73.

Everybody wanted a hand in the model. Senior editor Robert Burnham consulted with Jeff about topographic maps, and the two of them were soon poring over charts of lunar landscapes. Jeff selected the region around the Hyginus Rille as his subject. Art director Tom Hunt helped Jeff round up the supplies he needed, and soon Jeff's office was full of photocopies and sheets of cardboard. Jim Kelly and Gordon Odegard from our sister publication at Kalmbach, *Model Railroader,* helped Jeff with Hydrocal plaster and other "railroad" materials.

As the topography took shape from cardboard contour cutouts, Jeff predicted disaster, but he glued it all together anyway. I came down to watch as Jeff slathered Hydrocal plaster over the contours and Robert sprayed water — and was mesmerized to see precise lunar hills and valleys emerging from the slighty smelly and grubby white stuff.

If you want to try something that's a bit different, give topographic modeling a try. The fun's in the doing, and I guarantee that the model you make will put you in touch with astronomy.

Sincerely,

Richard Berry

Richard Berry
Editor-in-Chief

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ASTRONOMY

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## Letters

### Binoculars: A Great Way to Start

Deborah Byrd's Eye on the Sky articles are very helpful for beginners like me, and I particularly like the fact that they talk about objects that can be seen with binoculars.

The sky in Dallas isn't great, but I wanted to share with you my first "sighting" of the Pleiades, mentioned in the November issue. At first I couldn't see the star cluster, but when I raised my binoculars above Jupiter, the Pleiades popped out. So did the Hyades.

Thanks for articles that are helping me to get started in astronomy. — *Thomas E. Reynolds, Plano, Texas*

### New Version of ASTROCLK

I have been improving the ASTROCLK program for keeping sidereal time (Letters, July 1988). It is available free through a bulletin board system at (213) 541-7299.

If you don't have a modem, you can get a copy of the program, related data files, over eighty pages of documentation, and the complete QuickBASIC 4.00 source code, for $15 (for postage and handling) by writing to me. — *David H. Ransom, Jr., 7130 Avenida Altisima, Rancho Palos Verdes, CA 90274*

### Beyond the Confusion Limit

"Galaxies at the Confusion Limit" by Jeff Kanipe (December 1988) led me to an interesting possibility of what we are actually seeing at the confusion limit.

Many people believe the universe is really four dimensional and folds back on itself, so the universe is a finite but unbounded volume of space without the edges it would have if it were three dimensional.

One of the implications of this theory is that you could theoretically travel in a straight line away from Earth and eventually return to your starting point, the way you can circumnavigate the globe by traveling around Earth's surface in only one direction.

Assuming that light can travel the tremendous distances required to reach us, isn't it possible that one of the galaxies we see at the confusion limit is really our own Milky Way? — *Andrew S. Hanson, Glen Rock, Pennsylvania*

*— In principle this assumption is correct. A strange property of a closed universe is that if we set off in one direction (and are extremely long-lived), we would eventually arrive at our departure point from the opposite direction.*

*However, in looking out to the edge of the observable universe, we are also looking back in time, perhaps back 20*

# "Your Eyepiece Has Given Me the Most Pleasant Case of Insomnia Imaginable"

*Tom Lorenzin, author of "1000+ Guide to Deep Sky Observing"*

16MM NAGLER
12MM NAGLER
20MM NAGLER

**Discover Type 2 Nagler Eyepieces**

These new designs extend the Nagler concept to impressive new performance levels, while retaining the basic advances of the original Naglers:

—82° apparent field
—full field correction
—fast aperture correction, to f/4

**New Features Include:**

*First:* longer focal lengths produce wider true fields of view.
*Second:* full exit pupil correction permits comfortable night *and* day use.
*Third:* fold-down rubber eyeguards are included for maximum comfort and dark adaptation.
*Fourth:* they are relatively lightweight, moderately sized, and include knurled rubber grip rings for easier handling.

**Design Goals**

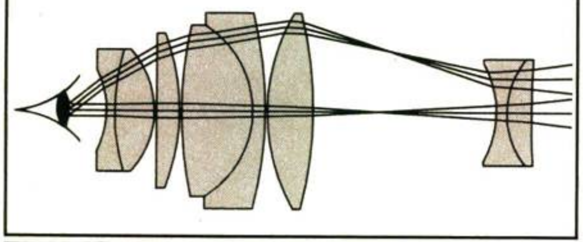
The basic Nagler series has already achieved image correction 10 times better than previous wide angle eyepieces (study in "Telescope Making" titled "The Nagler 13, a Remarkable Telescope Eyepiece"). We felt that extending the apparent field or image correction levels beyond that of the original Nagler series would *not* yield significant practical gains, but that extending the focal lengths *would* offer enormous potential for spectacular low power, wide-angle viewing.

In order to produce longer focal length Naglers, two practical limits had to be overcome:

1) Substantial physical size, weight, and cost increases would be impractical.
2) Scaling up exit-pupil aberrations would be unacceptable in our judgement. Although the 13mm Nagler eyepiece provides extremely sharp *images*, exit-pupil aberrations require a large (nighttime) eye pupil opening to encompass the full field. For this reason, daytime viewing with the 13mm Nagler is not recommended. Eye positioning is just too sensitive with the 7 element design to consider focal lengths longer than 13mm. The 9mm and shorter Naglers don't show this sensitivity.

**Nagler Type 2: The design breakthrough!**

The patented (#4,747,675) 8-element design achieves pupil aberration correction far beyond any eyepieces produced with such large apparent fields. Each model is a unique design, with eye relief similar to the 9mm Nagler, yet surprisingly compact, lightweight and affordable. Extensive computer-aided design efforts and the use of new glass types retain the superb full-field and fast aperture sharpness of the 7-element Naglers. Our pioneering lens edge-blackening and multi-coating techniques also maximize contrast.



A special rubber eyeguard aids viewing comfort, eliminating stray light and enhancing dark adaptation. This helps in detecting faint, delicate nebulosity and comets. The eyeguard is a delight on cold nights too.

**20mm Nagler Type 2**

Has the largest true field in the series. Yet this eyepiece, (strictly for 2 inch focusers) is comparable in size and weight to a 13mm Nagler. There's nothing like this 20mm for viewing large open clusters, galaxies and nebulae. It gives a 4.5mm exit-pupil with f/4.5 telescopes. Daytime viewing is also simply stunning!

**16mm Nagler Type 2**

Offers far more true field than the 13mm Nagler, yet is smaller and lighter. Great day or night performance with any telescope.

> *"There is nothing like this eyepiece (20mm Nagler) for viewing large deep-sky open clusters, galaxies, and nebulae. Under ideal conditions at Yosemite National Park, I was treated to incredible views of M8, M13, M17, M22, M31, and M33. I had believed that my C-8 would never perform visually with photographic quality, but my observations with the Nagler rivaled the detail in good astrophotography and even surpassed it at times. I was amazed and deeply satisfied. Thank you for the ultimate eyepiece."*
>
> Ben Cohen, CA

**12mm Nagler Type 2**

As superb as the 16mm, but with higher magnification. An excellent alternate to the 13mm Nagler, which has a longer eye relief for people who MUST wear eyeglasses to correct severe astigmatism.

The 16mm and 12mm Type 2 Naglers work beautifully with Tele Vue Barlows. These 1¼" barrel eyepieces can also be used with 2" focusers.

As Dr. Jack Marling says: "The eyepiece is half the telescope, so use the best... Tele Vue."

**Tele Vue™**

20 Dexter Plaza, Pearl River, NY 10965
(914) 735-4044

***WE'RE SERIOUS ABOUT HAVING FUN WITH ASTRONOMY.***

*billion years. If our Galaxy existed at the edge, we wouldn't be able to recognize it, because 20 billion years ago it had only just formed out of the primordial gas of the Big Bang.*

*A more serious problem with seeing the Milky Way at the observable edge of the universe is that light from our distant Galaxy would have had to go around the universe for us to see it now, but the time the light needs to do that exceeds the current age of the universe.*

*The biggest problem with this assumption, however, is that most astronomers assume that the universe is open and therefore would not curve back on itself.*

### Seeing the Green Flash

Last summer I learned the true meaning behind a statement made in "Optical Illusions of Low-Angle Observing" by Leendert de Witte (December 1988). In July I joined other amateurs at the Pine Mountain Observatory in Oregon, and on the second evening I watched and photographed the Sun as it set between two 10,000-foot volcanoes.

The Sun was actually setting on a distinct slope, so I was caught off guard when the green flash appeared. As the article stated, an extemely flat horizon is required to see the flash. But I learned that the trick is not to confuse "flat" with "horizontal." By not making this distinction, I missed a fantastic photograph but learned the difference. — *Jim Reilly, Portland, Oregon*

### Amateur Astronomers in the Classroom

As the father of a sixth grader and the owner of an 8-inch SCT, I felt a responsibility to bring astronomy into my local schools, so I spent two nights preparing an astronomical lecture to present to my child's class.

When I finally got in front of the class, I must admit I had a case of the butterflies. But once the lecture was under way, I relaxed and was able to answer questions from students and teachers alike, discard my outline, and feel satisfied with my knowledge of astronomy.

That night and the two following nights I conducted three-hour sessions with my telescope and was able to give these kids an opportunity to see the universe, an opportunity I never had as a child. — *M. C. McGowan, Tehachapi, California*

*ASTRONOMY welcomes comments, suggestions, corrections, and additional information on articles and astronomy. Send your letters to: ASTRONOMY Letters, 1027 North 7th Street, Milwaukee, WI 53233. Letters may be edited for length and clarity.* ☐

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## Viewpoint

# WHO WILL MISS THE NIGHT SKY?

*by David L. Crawford*
*Astronomer at Kitt Peak National Observatory and co-founder of the International Dark-Sky Association*

When the historians of the twenty-first century sit down to chronicle the present era, they will certainly not fail to notice the tragic irony of our times that goes largely unnoticed today: our intelligent, technically advanced society systematically trashed the Earth with pollution at the same time it was improving the quality of life in many other ways.

How can such a contradiction exist in a supposedly educated and able society? The answer, I think, is that we have stopped caring about our environment. Who notices how bad the water tastes? Who notices the litter in the streets and yards? Who cares about medical waste dumped into the ocean except those who want to lie on the beach now littered with that garbage?

> **It is painful for me to go out at night now, to see the bright skies surrounding our cities.**

Why don't more people see what we are doing to ourselves? Perhaps it is because we do not even have a word in our language for what is happening to the Earth. The Hopi Indians have such a word: *koyaanisqatsi*. One translation is "nature out of balance." Another might be "the Los Angeles freeway at 4 p.m. on a Friday afternoon."

When nature is out of balance, humanity loses. Whether it is the purity of the air or the beauty of the night sky, something we once had is taken away. I want to make everyone aware of these threats, and my special cause is the threat of light pollution.

I have been involved in combating light pollution for over ten years now, and each year I spend more time on it. At first it seemed to me that light pollution was an issue that only affected astronomers and then only the professionals at observatories involved with research on the very faintest objects. But it is clear to me now that it is not a specialized problem affecting just astronomers. Like all forms of pollution, any threat to the environment is a threat to all of us.

Because I have seen the splendor of a star-filled sky at prime dark-sky locations, I have a very keen sense of what has been lost to light pollution. It is painful for me to go out at night now, to see all the bad lighting and the bright skies that surround every urban environment. Most of the general public and even many people with an interest in astronomy don't feel this pain.

This sense of loss is what has made me a missionary, a light-pollution evangelist traveling the country for my cause. I want you to suffer from the same pain I do so you too will begin to actively care about what is happening to our environment.

Becoming sensitive to the tragedy of light pollution can be an unpleasant experience, but the tradeoff comes when you see progress being made through your efforts. And make no mistake about it, there is progress being made. When I look at what has been done so far, I am greatly encouraged. There are darker skies today in the Tucson area and other parts of the country where light-pollution activists have been at work. Future generations will benefit by what has been done and that should make everyone involved feel great.

But you cannot wait for others to solve the problem for you; there is not enough time for that. We need action now. We must all become activists, marketing the issues and solutions and educating locally, nationally, internationally.

There are many things you can do to help keep us moving in the right direction. Approach your neighbors about bad lighting, talk to city officials about establishing outdoor lighting control ordinances, give talks to community groups. These approaches work, and the results are satisfying. When people see there are reasonable, practical solutions to light pollution, victories can be won.

If you want to get involved in this crusade or just learn more about the problem, write to me in care of the International Dark-Sky Association. Tim Hunter and I founded this nonprofit organization last year to build awareness of the light-pollution problem and to share with others the materials, strategies, and solutions of light pollution activists.

So join us. You will be making the world a better place. ☐

*For more information on light pollution, write to the International Dark-Sky Association, 3545 North Strewart, Tucson, AZ 85726.*

# Cambridge University Press

## The Cambridge Atlas of Astronomy, Second Edition

***Edited by Jean Audouze and Guy Israel***

The most comprehensive and authoritative astronomy reference available, this invaluable guide is intended for amateur astronomers as well as anyone with a deep interest in space research and astronomy. This thoroughly revised edition has been meticulously updated to incorporate the latest developments. It includes the 1986 appearance of Halley's Comet; 1986 Voyager space probe encounter with Uranus; 1987A Supernova; and information on the newest telescopes.

***Approximately 1100 photographs and illustrations. Includes 350 color and 420 black-and-white photographs from the world's most prestigious observatories. Provides 330 color diagrams, 47 tables and 3 star maps. Oversized format.***

*1988 / 432 pp. / 36360-8 / Cloth $90.00*

## The Guide to Amateur Astronomy

***Jack Newton and Philip Teece***

This guide introduces all the fundamentals of astronomy with an emphasis on practical techniques. Newton and Teece provide an in-depth exploration into the field of astrophotography detailing techniques ranging from simple tripod photography to cold camera photography.

*1988 / 288 pp. / 34028-4 / Cloth $24.95*

## Atlas of Uranus

***Garry Hunt and Patrick Moore***

An historical background to the discovery of Uranus along with its satellites and rings is presented. It details the Voyager mission, allowing the reader to share in the quantum leap in our understanding of the new Uranian environment that has emerged from these encounters.

*1988 / 96 pp. / 34323-2 / Cloth about $14.50*

## Pathways to the Universe

***Sir F. Graham-Smith and Sir Bernard Lovell***

This illustrated introduction to astronomy starts from a level of common experience and develops the subject to the frontiers of modern research. The book explains how to become an astronomer and how to find your way around the sky using simple binoculars, telescope, or the naked eye.

*1988 / 244 pp. / 32004-6 / Cloth $24.95*

## Color Atlas of Galaxies

***James Wray***

Presenting color images of more than six hundred galaxies, this atlas offers a valuable source for both scientific investigation and aesthetic appreciation.

*1988 / 192 pp. / 32236-7 / Cloth $79.50*

## Superstrings: A Theory of Everything?

***Edited by P.C.W. Davies and J. Brown***

Based on the original transcripts of a BBC Radio 3 documentary, this book contains a clear and concise introduction to superstring theory that explains in non-mathematical terms the developments that led to the emergence of the theory and the profound consequences for physics if it should prove to be the "Theory of Everything."

*1988 / 234 pp. / 35462-5 / Cloth $34.50*
*35741-1 / Paper $10.95*

## The New Physics

***Edited by P.C.W. Davies***

Gives a complete and comprehensive account of everything that is new and most exciting in modern physics. Davies has collected specially commissioned chapters by eighteen top international physicists. Each article takes the reader to the leading edge of what is understood in that area.

*1988 / 450 pp. / 30420-2 / Cloth $39.50*

## Origins

***Edited by A.C. Fabian***

In this volume, a distinguished team of international authorities reports on the latest research on the origins of the most fundamental features of our world. Beginning with the "Big Bang", the book continues to focus on the origins of the solar system, material complexity and the human species.

*1989 / 184 pp. / 35189-8 / Cloth $19.95*

## NGC 2000.0

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***Edited by Roger Sinnott***

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# HEXAGON JET AROUND SATURN'S NORTHERN POLE

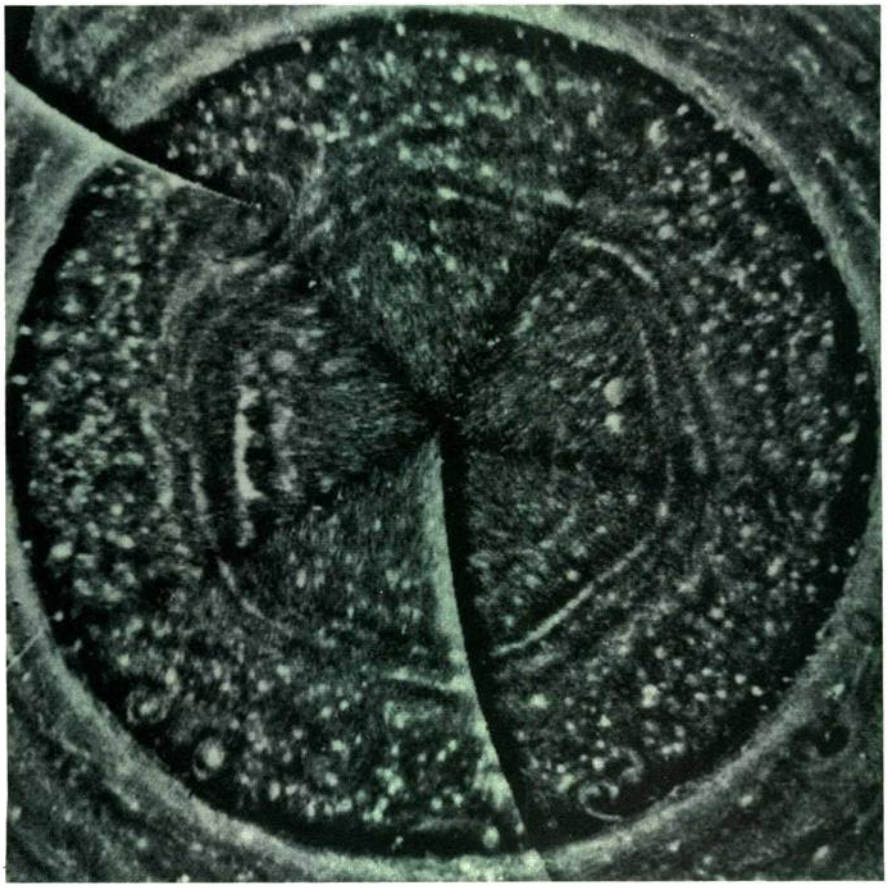
Saturn's high northern latitudes contain a cloud feature that makes a distinct and regular hexagon at a latitude of 76° and a distance from the pole of about 14,000 kilometers. Astronomer David Godfrey of the National Optical Astronomy Observatories found the feature on *Voyager* images of Saturn.

In their original form the photos showed the planet's north polar region severely foreshortened. Godfrey computer-processed the images to correct the geometric distortion. By combining separate photos taken as the planet rotated in front of the spacecraft's cameras, he made mosaics that show the entire north polar region and all parts of the hexagon.

The hexagon is a jet stream that has formed a standing wave pattern at a high level in Saturn's atmosphere; its straight sides are each about 13,800 kilometers long and the individual cloud streamers in the jet are flowing eastward at about 350 kilometers an hour. Despite a limited number of photos to work from, Godfrey was able to measure a rotation rate for the hexagon cloud pattern as a whole.

He found that the hexagon rotates around the pole once every 10 hours and 39 minutes. This is the same as Saturn's radio rotation period, determined from quasi-periodic changes in the planet's radio emission and thought to be the rotation rate of Saturn at a depth of about halfway to its core. The hexagon feature is thus some kind of channel at the cloud top that confines a jet stream flowing rapidly east while it rotates at the same rate as the deep interior of the planet.

What causes the hexagon feature? While Godfrey doesn't have a satisfactory explanation yet, he points out that Saturn's surface structure of belts and zones is believed to continue down to great depths, like nested cylinders or sleeves rotating around the planet's axis. The hexagon, he suggests, may be the surface expression of one of these.



**AN UNUSUAL HEXAGONAL** jet stream around Saturn's north pole points to a possible link between the planet's interior and the structure of the clouds at the top of its atmosphere. The dark "starfish" pattern marks the edge of the individual frames in this five-photo mosaic; the hexagon is not an artifact of the imaging.

## MARS: WHERE DID ALL THE $CO_2$ GO?

A mineral rarely encountered on Earth may be abundant in the Martian soil, and it may act as a reservoir for the carbon dioxide in the atmosphere of Mars. This finding has been reported by Roger Clark and Gregg Swayze of the U.S. Geological Survey and Robert Singer of the University of Arizona.

How Mars can store carbon dioxide in its soil is a problem that has challenged planetary scientists for years. The newly identified mineral, scapolite, fits the bill nicely, because it can store large amounts of $CO_2$ as carbonate in its crystal structure.

Clark, Swayze, and Singer identified scapolite on Mars by the close fit of the mineral's laboratory reflectance spectrum to the absorption features observed on Mars at five infrared wavelengths. No other mineral (out of hundreds tested) fits the observations so well.

Scapolite is an amber-colored semiprecious gem formed when carbonate rocks are metamorphosed by contact with molten volcanic rocks. The mineral has also been found on Earth in igneous rocks altered by fluids rich in carbon dioxide. The most likely Martian source for scapolite would be calcium plagioclase, thought to have been ejected by ancient volcanoes on Mars, combined with $CO_2$. Scapolite appears distributed all over the planet and is probably a component in the ever-present Martian dust.

## LIGHTNING SUSPECTED CAUSE OF VENUS' 'ASHEN LIGHT'

The mysterious "ashen light," a faint luminosity on the night side of Venus, may occur mainly in the Venusian evening and may be caused by lightning activity, according to a study carried out by John Phillips of Los Alamos National Laboratory and C. T. Russell of UCLA.

The ashen light, first noted in 1643, is one of the oldest observational mysteries in the solar system. (See Reader Reports, August 1988.) Phillips and Russell note that sightings of the ashen light are much more common during Venus' eastern elongations, when the planet is visible in the evening sky on Earth. This is when

# Take yourself on "an automated self-guided tour of the universe" with the Meade® CAT.™

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**What it is:** The Meade CAT ("Computer Aided Telescope") system is a revolutionary telescope accessory that leads Schmidt-Cassegrain telescopes from object to object, in *seconds.* The graphic display on the CAT's console enables the observer to locate *any object in the CAT's 8,199-object memory within, literally, 5 to 10 seconds or less.*

**How it works:** Included with the CAT are 2 precision optical encoders that mount on the telescope and sense the telescope's position in RA and Dec; the encoders permit the location of even the most obscure objects with 25 times the precision of standard setting circles. Using the CAT's large, red-illuminated crossline display, the observer manually moves the telescope to the position dictated by the crosslines. The CAT unerringly positions the desired object precisely in the center of the telescopic field. In addition, digital readouts on the display console continuously display R.A. and Declination.

**Object Database:** Included within the CAT's computer memory database are the positions of 8,199 objects — *virtually every object of interest in the entire celestial sphere, North and South:*

☐ **7,840 Deep-Space Objects,** including all 110 Messier objects, plus 7,730 other objects contained in the Computerized New General Catalog (CNGC) — galaxies, nebulae, star clusters, objects of every description in the sky.

☐ **351 Bright Stars,** used primarily as CAT reference objects, including 100 interesting double and multiple stars.

☐ **8 Major Planets:** The positions of all 8 major planets are included in the CAT's memory, a feature not available on any other computerized telescope system. In seconds you can locate Mercury, even in bright twilight; observe Uranus and Neptune; or photograph the day-to-day motion of 14th-magnitude Pluto. The CAT enables the positioning of these and the other major planets in the center of the field, *easily and rapidly.*

The Meade CAT attaches in minutes to Meade and other brands of Schmidt-Cassegrain telescopes and may be adapted by the user to other types of telescopes as well.

**Models and Pricing**

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| **CAT #9008:** | for Meade 2080/LX6 | **1495** |
| **CAT #9001:** | for all Meade 2120 models | **1495** |
| **CAT #9010:** | for Meade 2120/LX6 | **1495** |
| **CAT #9003:** | for C8 fork-mounted models | **1495** |
| **CAT #9005:** | for C11 | **1495** |

The CAT, shown on a Meade Model 2080/LX5.

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***Mode 3:*** enables a digital timer for timing astrophoto exposures.
***Mode 4:*** turns both registers "Off."

**Optical Encoders:** Meade Digital Setting Circles utilize Hewlett-Packard optical encoders for the highest level of precision and sensitivity. The encoders attach in minutes to the polar and Dec. axes. The readout unit mounts onto the telescope's rear cell, where it is *continuously visible from the eyepiece observing position as you move from object to object.*

**Models and Pricing**

| | | |
|---|---|---|
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| **DSC #9063:** | for C8 fork-mounted models | **495** |
| **DSC #9065:** | for C11 | **495** |

**Warranty:** Every Meade CAT and DSC unit is covered by a 3-year warranty on parts and labor.

**For further information:** Send for your free copy of Meade Bulletin CAT/DSC, or send $3.00 for the complete Meade **General Catalog #88C.** The 75-page CAT Instruction Manual is available at $5.00.

Better still, call or visit your authorized Meade dealer; he'll be glad to answer any questions on the Meade CAT and DSC's — two of the most exciting and revolutionary telescope accessories ever developed.

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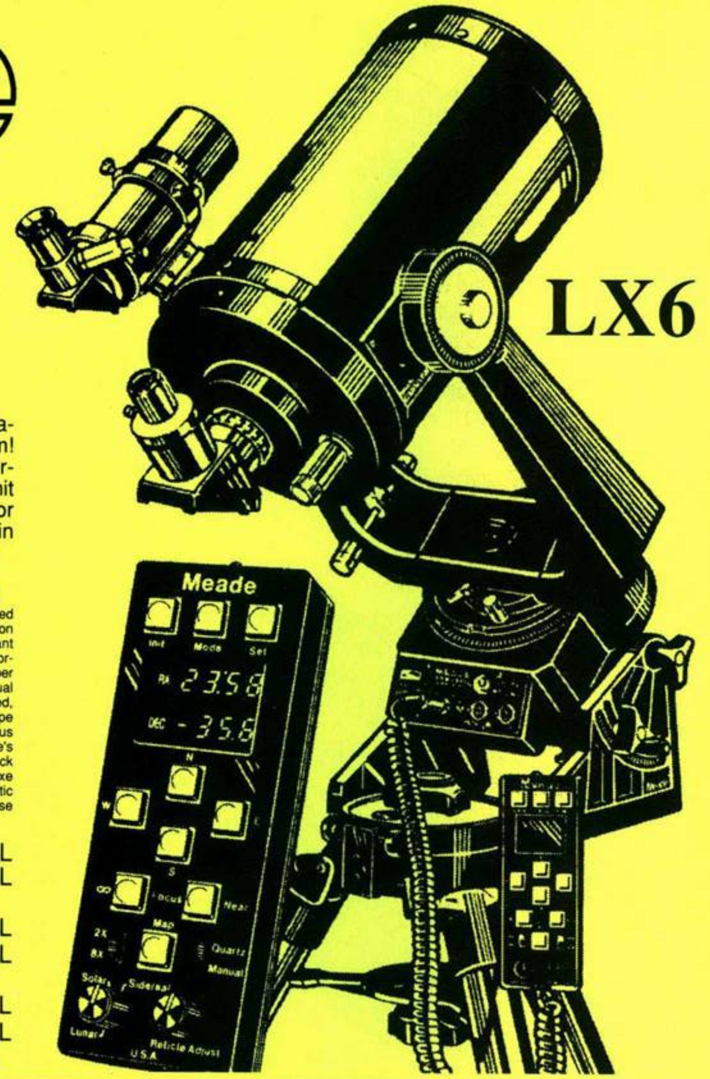

Meade's new LX6's boast an *f*/6.3 optical system which permits astrographic exposures in only four-tenths of the time required by an *f*/10 system! In addition, they come complete with quartz-locked, micro-computer-controlled, electronic pulse-motor drive, sophisticated hand control unit with astrographic drive correction functions built-in, 2.00" star diagonal for advanced, premium-grade eyepieces, giant 9x60mm finderscope, built-in provision for optional digital readouts or CAT system, and much more!

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Complete *f*/6.3 telescope tube assembly (8" or 10" aperture, 1,280mm or 1,600mm focal length), with certified diffraction-limited optical system; MCOG ("Multi-Coated Optics Group"), consisting of multi-layer anti-reflection coatings on corrector plate and enhanced reflectivity mirrors; ultra-smooth anti-backlash focus mechanism; giant 9x60mm illuminated-reticle polar-alignment viewfinder with quick-disconnect mounting bracket; 2.00" mirror-type star diagonal, with 1/10 wave multi-coated mirror and adapter for 1.25" eyepieces; Series 4000 26mm Super Plossl eyepiece, 1.25" (49x or 62x); rugged dual-fork astronomical mount with graduated setting circles, manual positioning controls and clutches on both axes of motion; digital quartz-locked, micro-computer-controlled, electronic sidereal-rate pulse-motor drive system and ultra-precision "LX" worm-drive gearing built into telescope drive base; Power Control Panel (also built into drive base) with controls, indicators and connectors for various accessory and auxiliary electronic equipment; Electronic Command Center hand-control unit (note: Meade's Digital Readout System is an ***optional*** accessory); 115Vac/60Hz power adapter with 25 ft. cord; DC battery-pack *(batteries not included)* with 4 ft. cord; 25 ft. DC power cord with automobile cigarette-lighter plug; Deluxe Equatorial Wedge with micrometric adjusters for latitude and azimuth, latitude scale, bubble level and magnetic compass; ultra-rigid adjustable-height Field Tripod; dust covers for optical apertures; foam-lined carrying case for scope-tube/fork-mount/drive-base assembly; instruction manual; limited lifetime warranty.

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| 2080 LX6 | (List: $ 4,400) | CALL |
| 2120 LX6 | (List: $ 6,400) | CALL |
| Optional Digital Readout System: | | |
| Mod. 9068, *for* 2080 LX6 | (List: $ 590) | CALL |
| Mod. 9070, *for* 2120 LX6 | (List: $ 590) | CALL |
| Package: Telescope *and* Optional Digital Readout System, together: | | |
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| 2120 LX6 *with* Mod. 9070 | (List: $6,990) | CALL |

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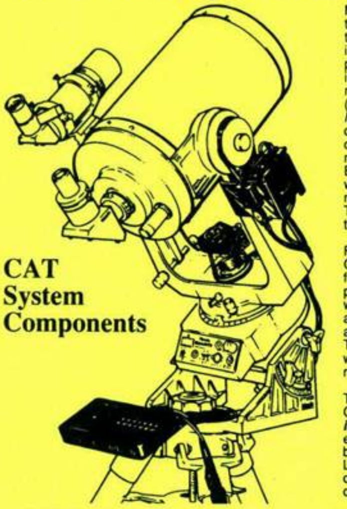
## Meade's Computer-Aided Telescope System

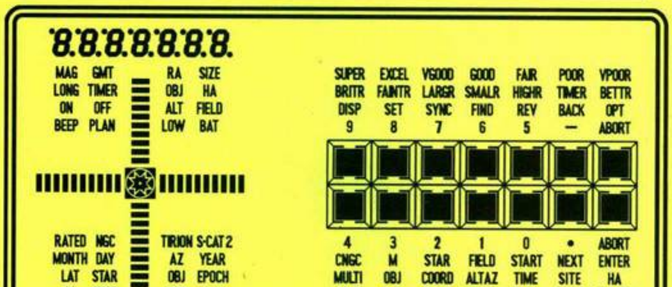


CAT System Components

Meade's **C**omputer-**A**ided **T**elescope (the "CAT") system has most of the advantages of a computer-controlled telescope at only a fraction of the cost. Consisting of a specially-designed, high-speed, extremely powerful computer, along with a pair of high-resolution incremental shaft encoders and their associated mounting hardware, drive components and cabling (*see general arrangement drawing at left, and panel layout drawing at right*), the CAT can readily and quickly direct you to any of the thousands of celestial objects whose coordinates and other descriptive information are permanently stored in its 1Mb plug-in EPROM database, ***including all of the planets***, as well as to any other celestial object of known coordinates (comets, asteroids, quasars, super-novae, etc.). The computer is loaded with extra features and functionality as the panel legends, at right, indicate.

For the computer-literate, there is also a version of the CAT available with an RS-232C port (the "CAT-COM") for connection to a "PC" compatible personal computer. CAT-COM includes four "demonstration" software subroutines, written in BASIC, to show you how to address and control the CAT from your own computer, as well as the necessary RS-232C interconnect cable. The software is supplied on a 5.25" 360Kby diskette, with backup source-code listings in the instruction manual.

The CAT is available for most fork-mounted Schmidt-Cassegrain telescopes, but has been ***electronically integrated*** with the new LX6 series, so that the encoders and the CAT computer plug directly into the drive-base. Consequently, during our introduction of the LX6 series telescopes, we are offering extra savings on packages consisting of an LX6 telescope and one or the other of the CAT systems.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STAR GAL PNEB DNEB GLOB OPEN TYPES

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| Optional Computer-Aided Telescope (CAT) System: | | |
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| CAT-COM *for* 2080 *or* 2120 LX6 | (List: $2,290) | CALL |
| Package: Telescope *and* Optional CAT System, together: | | |
| 2080 LX6 *with* CAT | (List: $6,390) | CALL |
| 2080 LX6 *with* CAT-COM | (List: $6,690) | CALL |
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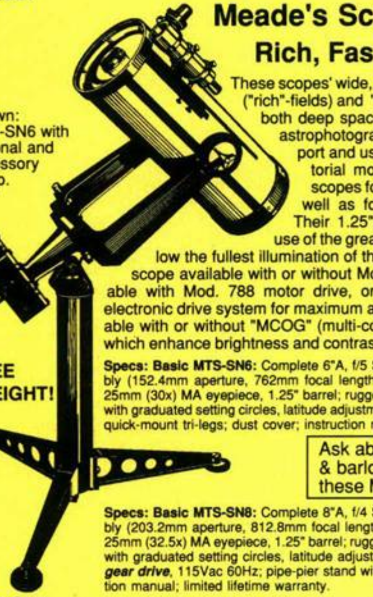

Shown:
MTS-SN6 with optional and accessory equip.

These scopes' wide, bright, highly corrected fields of view ("rich"-fields) and "fast" focal ratios make them ideal for both deep space visual observing and prime focus astrophotography. Easy and convenient to transport and use because of their "fork" -type equatorial mounts, they are excellent all-around scopes for those just starting in astronomy, as well as for experienced astrophotographers. Their 1.25"/2.00" focusers not only permit the use of the greatest variety of eyepieces, but also allow the fullest illumination of the film-plane during photography. 6" scope available with or without Mod. 788 motor drive. 8" scope available with Mod. 788 motor drive, or "LX3" quartz-synchronized micro-electronic drive system for maximum accuracy and precision. All are available with or without "MCOG" (multi-coated optics group) optical coatings, which enhance brightness and contrast of visual and photographic images.

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| MTS-SN6 | (List: $ 1,050) | CALL |
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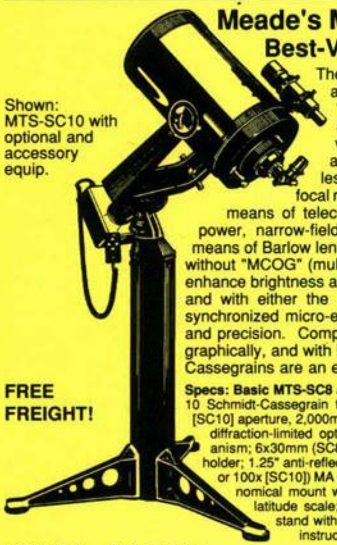

Shown:
MTS-SC10 with optional and accessory equip.

These scopes' "general-purpose" f/10 focal ratios and modest prices make them the best-value "all-purpose", "do-everything" scopes available. Optically capable of delivering exquisite views and photographs of almost all types of astronomical objects "as-is", they may nevertheless be extended to extremely "fast" effective focal ratios and correspondingly wide fields of view by means of telecompressor accessories, or to extremely high power, narrow-field lunar, planetary and multiple-star work by means of Barlow lens accessories. Each scope is available with or without "MCOG" (multi-coated optics group) optical coatings, which enhance brightness and contrast of visual and photographic images, and with either the Mod. 788 motor drive, or the "LX3" quartz-synchronized micro-electronic drive system for maximum accuracy and precision. Compact, portable, easy to use visually and photographically, and with Meade's high-quality optics, the MTS Schmidt-Cassegrains are an extraordinary value in astronomical telescopes.

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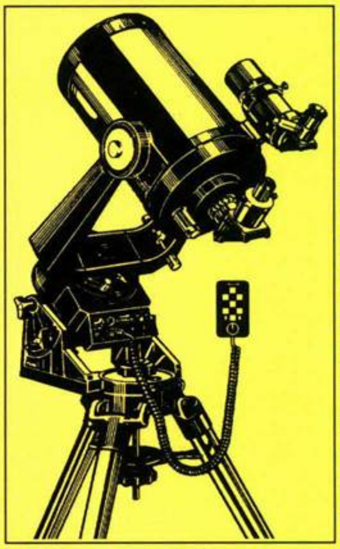

## Meade's LX5's

Fully equal to LX6's in terms of their standard equipment, they come complete with quartz-lock microelectronic pulse motor drive, sophisticated hand control unit with photographic drive correction functions built-in, 2.00" star diagonal for advanced, premium-grade eyepieces, & giant 9x60mm finderscope!

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| | | |
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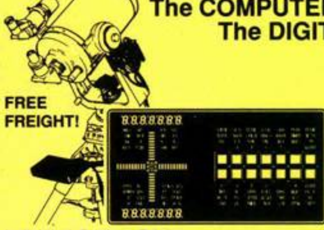

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Venus turns its evening side toward us.

Looking for a physical cause for the Venusian evening sky glow, Phillips and Russell suggest that the ashen light may come from lightning, which radio instruments aboard the *Pioneer Venus* spacecraft have detected indirectly. These detections show that lightning occurs most frequently just after local sunset. An alternate explanation they propose is an aurora, caused when solar wind particles preferentially strike the leading hemisphere — which is the evening side of the planet — as it orbits the Sun.

Phillips and Russell admit that many more observations (positive and negative) exist for evening elongations of Venus than for morning, but they believe the local-time asymmetry in ashen light sightings is real. However, Phillips cautions, "Using either lightning or aurora to explain the ashen light gets you into an energy problem," he notes, "but lightning would have to be only a little stronger than on Earth to explain the ashen light. Aurorae, however, are far too weak to generate the glows that observers claim to have seen."

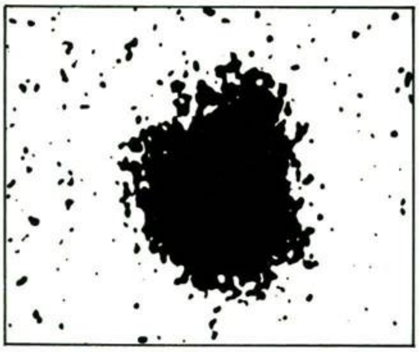
## DISCOVERY OF PLUTO'S MOON AN ACCIDENT?

The discovery of Pluto's moon Charon in 1978 by James Christy (see photo) was not as much a lucky find as the natural result of a favorable viewing geometry and developing technology, according to astronomer Robert Marcialis of the University of Arizona's Lunar and Planetary Laboratory.

Several advances in astrometry — the science of measuring precise stellar and planetary positions — paved the way for Charon's discovery. First, the completion of the U.S. Naval Observatory's 61-inch astrometric reflector in 1964 let astronomers capture enough light to take photographic plates with short exposures. These produced images that were less blurred by atmospheric seeing.

Second, the development in the 1960s of automated machines to measure astrometric plates removed the personal errors that limited the precision of manual measuring techniques. The combination of measuring machines and shorter plate exposures emphasized the use of "small-image" plates, ones where the image of the star or planet is not an overexposed, saturated blob.

"Once exposure times were cut down," Marcialis said, "it became possible to resolve many binaries — both for stars and in the case of Pluto, for a planet — that had previously been burned into the plate emulsion."



**PLUTO'S MOON CHARON,** a small asymmetric "blob" on the image of Pluto: found when the time was right?

Viewing geometry played a role as well. Pluto's orbit is oriented so it reaches its greatest northern declination during the inbound quarter of its 248-year circuit of the Sun; Pluto is at perihelion on September 5 this year. A high northern declination creates a "window" of good viewing conditions for Northern Hemisphere observatories, where most astrometric measurements involving Pluto have been done. (Pluto was farthest north in 1946 and has been moving south ever since.) In 1946 the observing window for high-quality plate taking was about 8 hours wide; in 1990, it will be only 4 hours wide.

Charon's orbital orientation is also important. "A satellite orbiting face-on — as the Uranus system is right now and Pluto/Charon were in the 1940s — offers a much better chance of being found," claims Marcialis. "Every single night the moon will lie at some good elongation from its primary." At present, however, we see Charon's orbital plane nearly edge-on. "Right now you can see the Charon 'bump' on only two nights per orbit, less than a third of the time."

Between the 1940s and 1978, therefore, Charon was becoming less easy to detect. In the 1940s Charon's orbit put the moon in an excellent position to be discovered, but plate measuring techniques demanded long-exposure photographs that ensured Charon was hidden in the enlarged image of Pluto.

Years passed and Charon developed a larger angular separation from Pluto as the pair approached perihelion. But the nights on which Charon was at a good elongation were steadily becoming fewer as the moon's orbital plane moved closer to our line of sight. Independently, however, instruments and techniques underwent a fundamental change that for a critical period at least, more than compensated.

Marcialis is convinced that Charon was found when the time was ripe. "Although Charon's orbit may have been less optimal in the 1970s than in previous decades, in a relative sense, the geometry was much more conducive to finding Charon back then than it would be today."

## CORNELL AND CALTECH TO SHARE 200-INCH TELESCOPE

Cornell University has joined the California Institute of Technology in operating the 200-inch Hale telescope on Palomar Mountain. Caltech has owned and operated the telescope since its completion in 1949. Cornell astronomers will receive one fourth of the observing time on the telescope in return for providing one fourth of the operating costs and constructing new instruments for the telescope.

"This agreement assures that the Hale telescope will remain at the forefront of science," said Caltech president Thomas Everhart. Cornell president Frank Rhodes said, "The opportunity to make use of this extraordinary telescope is extremely valuable to us. We are grateful that Caltech has offered Cornell astronomers access to the Hale telescope."

"We are extremely pleased with this agreement," said Palomar observatory director Gerry Neugebauer. "Currently the most significant restriction on the 200-inch telescope is the limited array of instruments available to astronomers. The agreement with Cornell will enable us to have new detectors that will provide benefits to all observers."

Cornell astronomers have pioneered the development of sensitive new infrared detectors for ground-based and orbiting telescopes. Cornell will now build a mid-infrared spectrograph for the 200-inch telescope. At wavelengths of roughly 10 micrometers, the instrument will analyze radiation from cool objects in space — forming and newborn stars, comets, planetary atmospheres, and young galaxies.

## THE VANISHING STAR

Imagine looking through a telescope at a star and seeing that star suddenly disappear. That is what happened one night last July to Reinhold Hafner of the Munich University Observatory in West Germany. The surprising observation, however, has provided some unique data on how certain binary star systems may evolve.

Hafner was observing the 17th-magnitude star PG 1550+131 in Ophiu-

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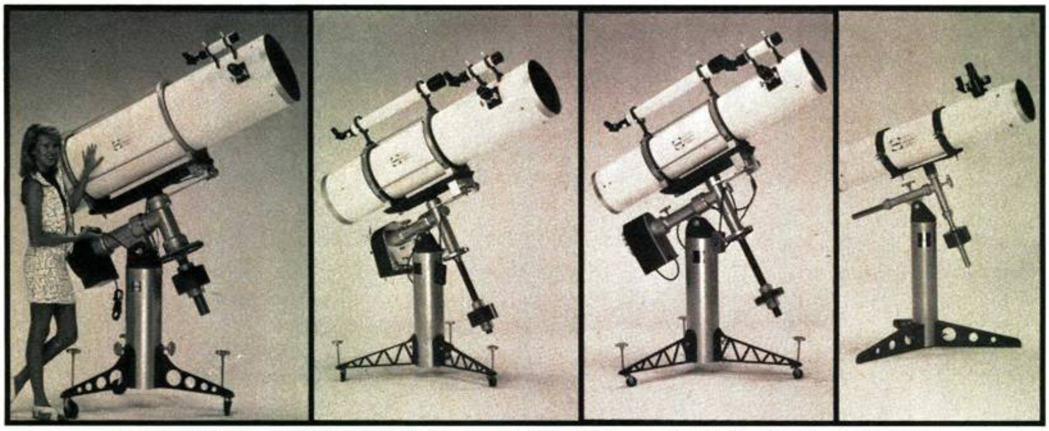

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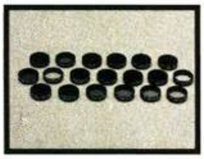

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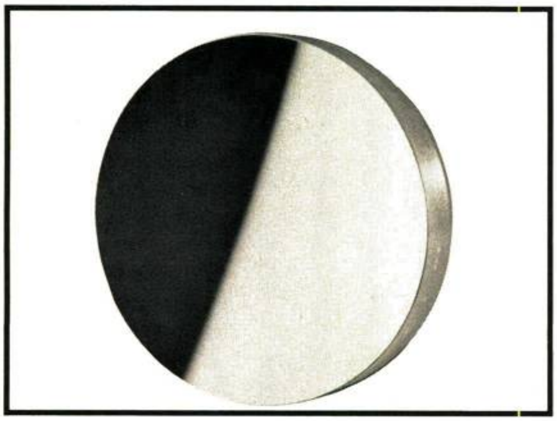

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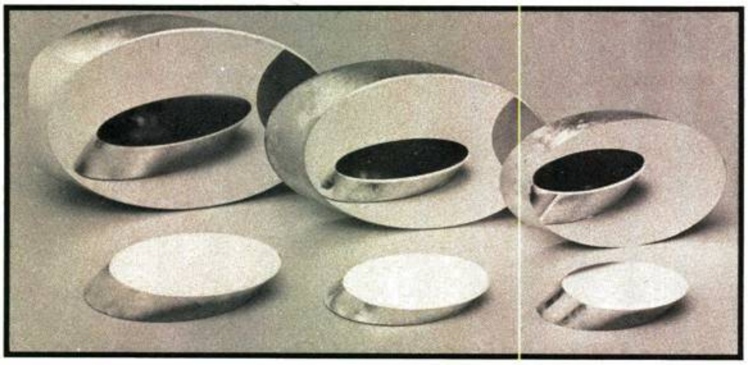

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chus with the Danish 1.5-meter telescope at the European Southern Observatory in La Silla, Chile, when it disappeared. Knowing that a star cannot literally vanish, Hafner concluded that the star was in a binary system and had been eclipsed by an unseen companion.

His next surprise came when the star reappeared a few minutes later. Hafner had just witnessed the most complete and fastest stellar eclipse ever seen. During that and the following night he observed two more eclipses.

Hafner became interested in the star after earlier observations implied that it might belong to the relatively rare class of stars known as "cataclysmic variables." These are binary systems in which one star has evolved into a white dwarf and the other star is a normal main sequence star that orbits close to the white dwarf. A steady stream of gas from the larger star to the white dwarf builds up on the white dwarf's surface until the gas becomes hot enough to undergo nuclear burning. There follows an explosive release of energy, which causes the system to brighten suddenly.

But PG 1550+131 appears to be at a stage immediately preceding the cataclysmic variable phase. Less than two dozen of these "precataclysmic variables" — in which gas has not yet begun to flow between the two components — are known, and little accurate data exist on the stars in this transition phase.

The pronounced eclipses in PG 1550+131 give astronomers the chance to get more data on this type of system. By analyzing exactly how the system's light changes during the eclipses, astronomers can determine the sizes of the stars, the size and shape of their orbit, their temperatures, and other physical properties.

Preliminary results show that the amount of light lost during the eclipse is a record 99 percent or more. This means the main sequence star — the one with its light remaining during an eclipse — is less than one hundredth as bright as the white dwarf. The short duration of the eclipse, also a record, means the companion must be a small, cool red dwarf star, with a temperature of about 3000 kelvins. The side of the red dwarf facing the white dwarf, however, is twice as hot, about the same temperature as that of the Sun. The white dwarf has a surface temperature of about 18,000 kelvins.

The entire system is very small. The orbital period of the pair is 187 minutes, and the distance separating the components is slightly over 400,000 miles. Thus, the entire binary system could fit comfortably inside the Sun.

## Space News

# NASA PONDERS THE MARS ROVER

How would a robotic sample-return mission to Mars be launched if the hardware were too heavy for a single rocket? How accurately does the Martian surface have to be mapped before a craft can land safely on it? How smart does a surface rover have to be to navigate around Mars on its own?

These are just a few of the questions NASA has begun to investigate as it maps out its strategy for the Mars Rover/Sample Return mission. An initial study of the mission, conducted by the Johnson Space Center and the Jet Propulsion Laboratory, was completed last fall.

"Defining just what this mission is, is not a trivial problem," said Mark Craig, deputy manager of the Johnson study team. "The mission has a complicated set of requirements. Aside from the science objectives at Mars, it will demonstrate technologies required for manned missions and it may also involve international cooperation."

The study evaluated several different scenarios that would leave Earth in the late 1990s and return in less than three years. The mission's four hardware elements — an orbiting satellite to map the landing site and communicate with Earth, surface rover, ascent vehicle, and orbiting return craft — would be launched aboard two Titan IV rockets.

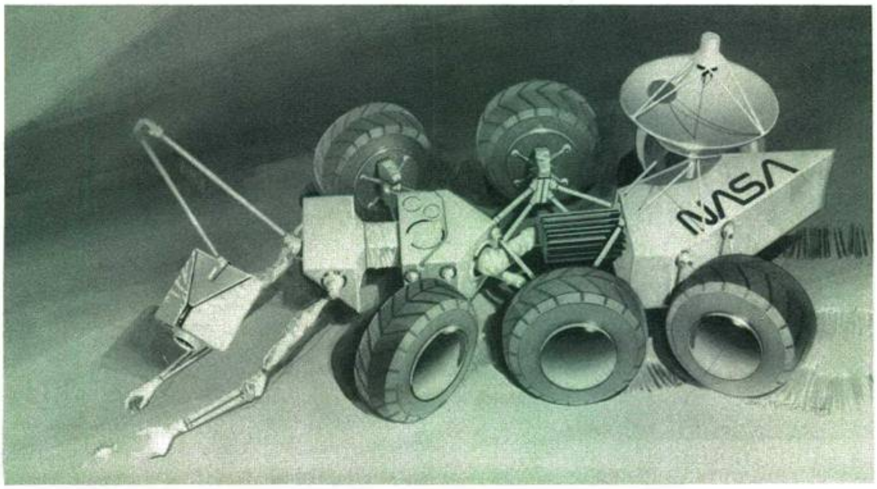
Before the rover or ascent vehicle land on Mars, the orbiter, using a 1-meter-diameter telescope, photographs the six-mile-square landing area at a resolution that will detect objects as small as one yard across. This allows for a safe landing and the ability to preplan the rovers movements on the surface.

The rover spends five months gathering up to one hundred samples of Martian soil, rock fragments, pebbles, and subsurface material. With a "multispectral imaging system" on board, the rover would be able to identify the composition of objects it sees on the surface.

After the rover lands, the ascent craft that will take the samples into Mars orbit makes a pinpoint landing near the rover. The rover makes a series of trips out to selected sample sites and returns to deposit the samples in the ascent craft.

Following a path based on the orbiter's high-resolution images, the rover first surveys the area ten yards ahead of it, analyzes the scene to find a safe route, moves ten yards ahead, stops, and repeats the process before going farther. As the rover proceeds to its destination, it searches for interesting samples to pick up on its way back to the ascent vehicle.

Other aspects of the mission examined include the method for retrieving samples at Earth and the possibility of launching the rover and orbiter two years before the return vehicle to allow the rover more time on Mars. NASA is continuing to study all aspects of the mission.



**COLLECTING MARTIAN SAMPLES** may be done with the aid of a sensor that can detect the composition of objects it sees as the rover travels across Mars.

# THE SS80: MORE THAN JUST A SPOTTING SCOPE!

Originally marketed as a terrestrial spotting scope, the SS80 has come into its own as an astronomical telescope. With its low power, wide field of view, the SS80 is ideal for observing deep sky objects. With the standard 18mm Orthoscopic eyepiece, you get a 2.1° field of view. The large, 80mm objective lens is multi-coated to ensure crisp, bright images. And, with a focal length of 400mm, the SS80 offers enough power to obtain good image size.

For casual astronomical viewing, the SS80 can be mounted on a photographic tripod. Or, with an optional T-adapter, you can convert the SS80 into an f/5 telephoto lens—**ideal for piggyback astrophotography.**

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# Amateur News

## HISTORIC REFRACTOR BACK IN USE

Members of the Southeastern Iowa Astronomy Club have refurbished a 12-inch f/15 refractor made in 1937 by Alvan Clark & Sons. Clark refractors are legendary for their unexcelled performance, and only a few hundred were made during the firm's existence. The Iowa telescope sat unused and in disrepair for more than a decade until saved by the enterprising amateurs.

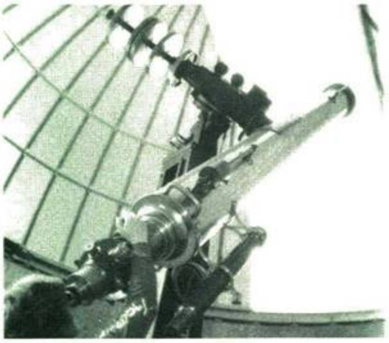
Dave and Marion Bachtell, members of the Burlington, Iowa-based group, explained that the club knew the Burlington Community School District owned a large Clark refractor. The telescope had been donated to the district in 1939 by a local amateur astronomer named John H. Witte.

"In the early 1970s," the Bachtells said, "the district built a new high school with an observatory housing a 16-inch Cassegrain scope, and the Clark was mothballed. At a club meeting in the mid-1980s someone jokingly suggested that we acquire the Clark and build an observatory for it — and soon after we stopped taking it as a joke."

The school district agreed to donate the telescope to the club if members could come up with the land and the money required to build and operate an observatory. The Witte Foundation provided a grant for constructing the observatory building. Club members interested the Des Moines County conservation board in an astronomy program, and Des Moines County agreed to donate the land. After a final meeting between all parties, work on the observatory began in June 1985.

The club then had an enormous project on its hands. The telescope was in reasonably good shape but needed general cleaning, reassembly, and testing. The Bachtells cleaned the focuser assembly. Members Duane Gerling, Jim Blair, and Claus Benninghoven carefully cleaned the fragile objective lens. Meanwhile Bob Carhoff and Jim Hilkin supervised work at the observatory.

"In late summer 1986, after many evenings and weekends of backbreaking work, we saw 'first light' with the refurbished Clark refractor," said Marion Bachtell. "The images were very impressive. The first night we used the telescope we looked at Saturn, which was incredible. The planet's globe filled the field."



**POINTING SKYWARD ONCE AGAIN,** a refurbished 12-inch Clark refractor peers out of its dome near Burlington, Iowa.

The Burlington club now uses the observatory for a variety of observing projects and holds public viewing twice a month. Numerous school and scout groups have visited the observatory for stargazing sessions. Club members are proud to have revived an old telescope and made it available to show the public the universe.

### IRISH AMATEURS GATHER AT BIRR CASTLE

Amateurs in the Republic of Ireland held their second annual Whirlpool Star Party between September 16 and 18, 1988. The meeting took place in Birr at Birr Castle, where in 1845 the third earl of Rosse, William Parsons, discovered the spiral appearance of some galaxies. Despite cloudy skies, amateur astronomers presented an array of talks covering many topics in professional and amateur astronomy.

The meeting opened with an address by the current earl of Rosse, the great-great grandson of Parsons. The earl anticipated an exciting future for astronomy at Birr Castle. He intends to continue the star party and refurbish as much as possible of his famous relative's equipment and create an astronomical museum.

Talks ranged from space exploration to solar observing to drawing deep-sky objects. Peter O'Connell of the Irish Astronomical Association described the inner workings of the space shuttle, using NASA plans and highlighting the differences between the new and old shuttle designs. O'Connell included an analysis of the solid rocket booster O-rings and allowed the audience to decide whether or not the *Challenger* disaster could have been prevented. After O'Connell's talk, well-known English astronomer Ian Ridpath spoke on intelligent life elsewhere in the universe, drawing on statistical arguments and explanations of the conditions under which life might form.

Other amateurs presented talks with observational themes. John Smith of the Irish Astronomical Association outlined his methods for observing the Sun, including a step-by-step guide on how to safely observe the Sun's disk with front-fitting filters or safe eyepiece projection. Smith showed stunning photos he had made of enormous sunspots during last summer's rise in solar activity. Alan Dowdell of the British Astronomical Association described his methods for sketching deep-sky objects and demonstrated techniques with a pad of paper and a soft pencil.

The star party's last day featured a tour of the Birr Castle grounds led by the present earl of Rosse. He opened the castle's instrument room, which contains a device that Parson's son Charles, the fourth earl, used to first measure the amount of heat reflected by the Moon.

The convention ended later in the day as a group of tired astronomers, disappointed with the weather but excited by the talks, packed up and went home until next year's gathering. With the second Birr Castle star party behind them, many attendees felt that amateur astronomy in Ireland is gathering steam. — *Tony O'Hanlon*

### HAS CLYDE TOMBAUGH VISITED YOU?

Clyde W. Tombaugh, the discoverer of Pluto, is keeping a busy schedule these days. Although he is more than eighty years old, Tombaugh is regularly speaking at astronomy clubs, pleasing audiences with stories of his 1930 discovery of Pluto.

The proceeds of Tombaugh's talks are deposited in the Clyde Tombaugh Scholars Fund. This account was established two years ago to help young people pursue astronomy at New Mexico State University in Las Cruces.

Astronomy clubs can help raise money for the Scholars Fund by having Tombaugh speak at a club meeting. For more information on this program, contact Bernard McNamara, Department of Astronomy, New Mexico State University, Las Cruces, NM 88003, telephone (505) 646-4438 — *David H. Levy* □

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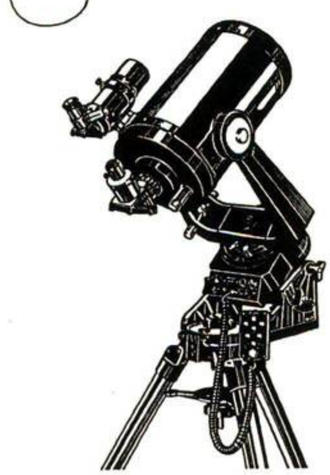

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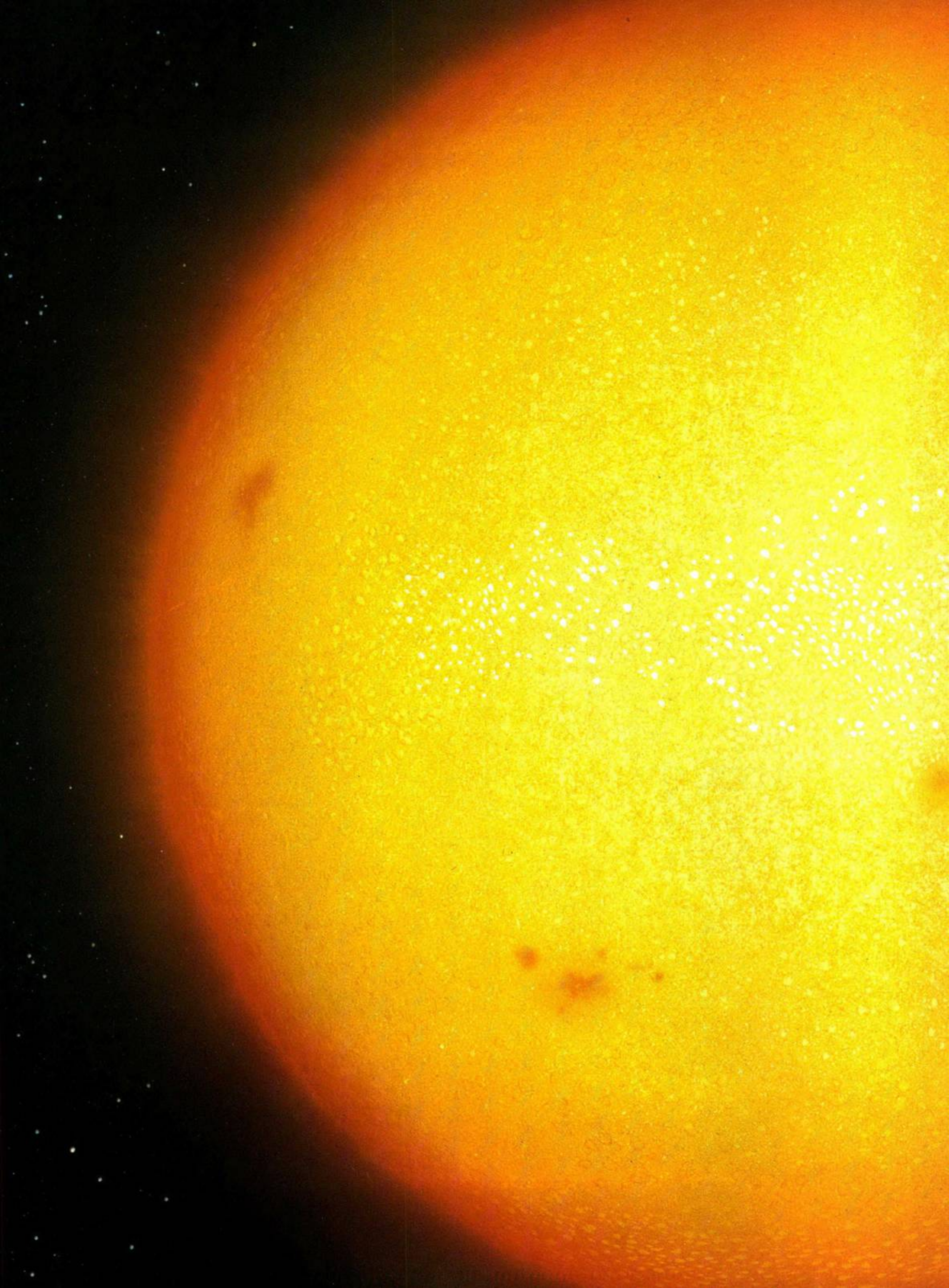
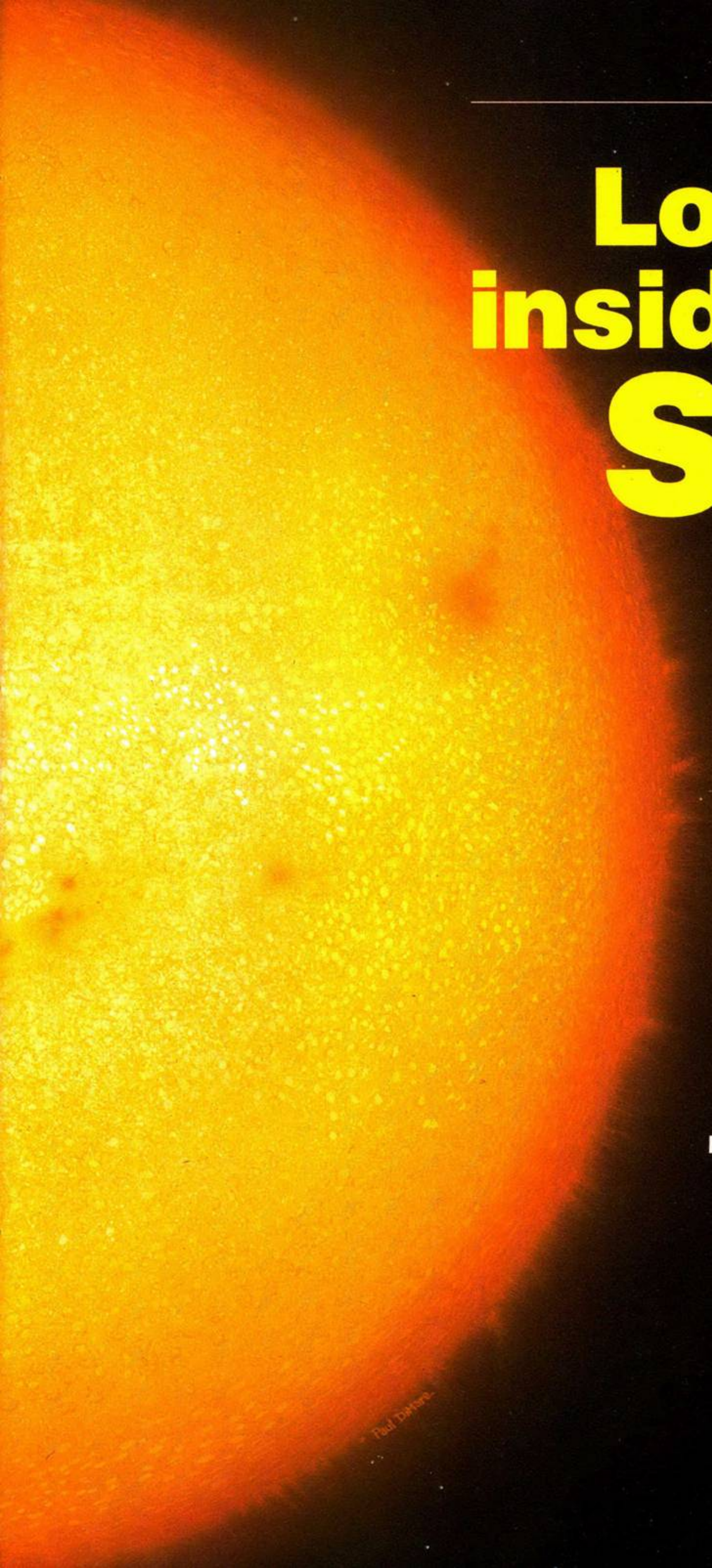


# Looking inside the SUN



The internal workings of the Sun are not well understood by astronomers. But when it was discovered fifteen years ago that the solar surface constantly quakes, astronomers had found a way to probe the interior of the Sun. By studying the seismic waves that shake the surface, astronomers are developing a picture of the Sun that may revolutionize how we look at our neighboring star and stars in general.

by James Charles LoPresto

Over the last few decades research on the Sun has unsettled many solar astronomers because basic observations of the Sun's properties have come into serious conflict with theoretical predictions. Astronomers are having to face the idea that much of what they believed true about the Sun's interior is questionable at best or even downright wrong.

The problem is that "paper Suns" — theoretical models for how the Sun works — no longer predict the real Sun with accuracy. For instance, we are not detecting more than a third of the solar neutrinos — tiny, massless particles generated in the Sun's thermonuclear reactions — that we should be detecting. Something is obviously wrong, but is it the Sun or our knowledge? Other problems are equally basic: Is the Sun's core rotating? How fast? Do we know its central temperature? How dense is each layer of Sun from the center out? Is the solar diameter contracting or has it remained essentially the same size over the past few billion years?

**Important parts of our models for the Sun's interior are questionable or downright wrong.**

Up until now everything known about the Sun has been derived solely from observations of the Sun's surface, and theoretical projections offer the only way to explore the unseen regions below. In the last ten years, however, this situation has changed with the blossoming of a new field of solar research: helioseismology, a science that studies solar vibrations — "Sun quakes." Because these waves travel through the Sun's interior, they give astronomers a way to "see" beneath the solar surface. Just as geophysicists use earthquake waves to probe the deep structure of the Earth, astronomers can now begin to x-ray the Sun with sound waves. The outcome of this revolution in solar physics will be a new and much improved model for the Sun. It is badly needed and long overdue.

First, however, let's look at a few failures, places where the standard solar model has broken down or can't tell us what we need to know.

### How Hot Is the Sun's Core?

The standard model predicts that in the proton-proton nuclear chain reactions that power the Sun, a certain number of high-energy neutrinos will be released. Neutrinos are subatomic particles with very peculiar properties. They travel at the speed of light, have no mass, and can penetrate entire planets unimpeded.

Since the late 1960s Raymond Davis of the Brookhaven National Laboratory has been looking for solar neutrinos from the bottom of a gold mine in Lead, South Dakota. His "telescope" is a 100,000-gallon tank of cleaning fluid. When high-energy neutrinos pass through the fluid, they induce minute changes that can just be detected by careful analysis. Year after year Davis and his coworkers have been carefully filtering the fluid, looking for traces of solar neutrinos. If the models for the Sun that predict a central temperature of 15 million kelvins are correct, Davis' telescope should be detecting about one solar neutrino a day. His problem — and that of solar physics — is that the actual count remains stubbornly at about one third of that.

The "neutrino problem" has caused spirited debate among astronomers and physicists for about twenty years. Many explanations have tried to account for Davis' low counts. Most have sought to reconcile the Sun's observable surface properties with a lower central temperature. But the nub of the problem is that while a temperature of about 13 million kelvins at the solar core would agree with the observed neutrino count, a lower core temperature also means the Sun should *look* different than it does.

Because knowing the exact neutrino count is so important, a new experiment using gallium instead of cleaning fluid has been proposed. This experiment could detect lower-energy neutrinos, which are more numerous. This should give better results because the larger number of neutrinos would produce more detections, thereby giving theoreticians more data to work with. However, the new experiment demands far more gallium than physics budgets can afford at present and so it has been shelved indefinitely.

Theoretical physicists have not remained aloof from the battle either. Some suggest that neutrinos come in three different types capable of oscillating from one type to the next. Davis' numbers seem about right, they think, because his experiment can detect only one of the three proposed kinds of oscillating neutrinos. But this explanation is highly controversial, and no one working on the problem feels comfortable relying on it to resolve the observed discrepancy. In the end, careful analysis of Davis' difficult experiment produces the conclusion that either the Sun really does emit fewer neutrinos than the models predict or that our knowledge of neutrinos is too deficient for us to be absolutely sure this experiment correctly samples them. Whichever the case, solar physics has a problem that can be resolved only by getting a better look inside the Sun.

### Does the Solar Core Rotate?

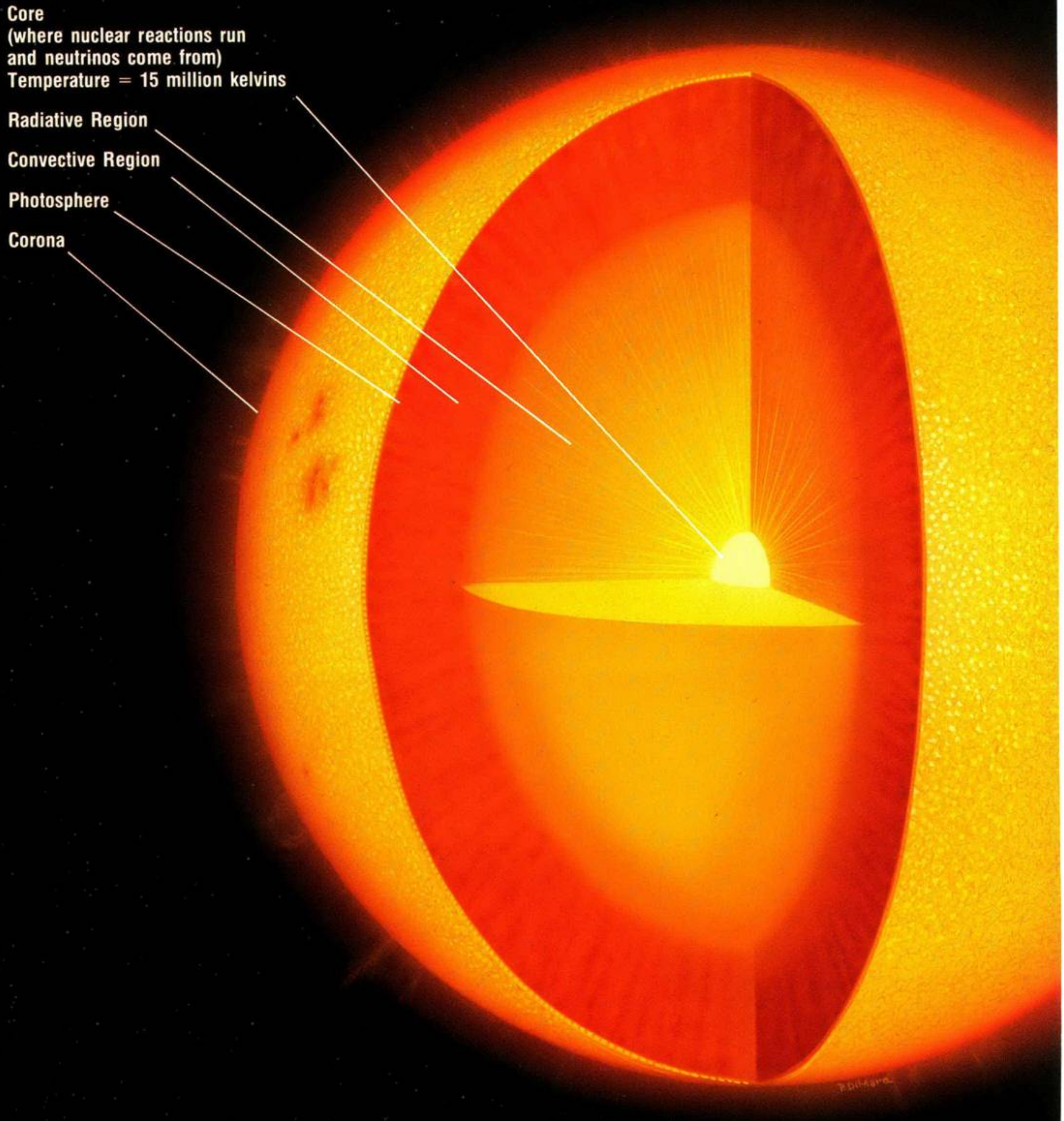
Missing neutrinos pose one kind of difficulty; another concerns the motions of the solar interior. For instance, is the solar core rotating? The models don't say, but an answer of sorts came in the 1960s from Robert Dicke and his colleagues at Princeton University. Dicke, in fact, was after much bigger game than solar modeling. He and another physicist had devised an alternative to general relativity and a crucial test of the theory concerned the precession of Mercury's orbit.

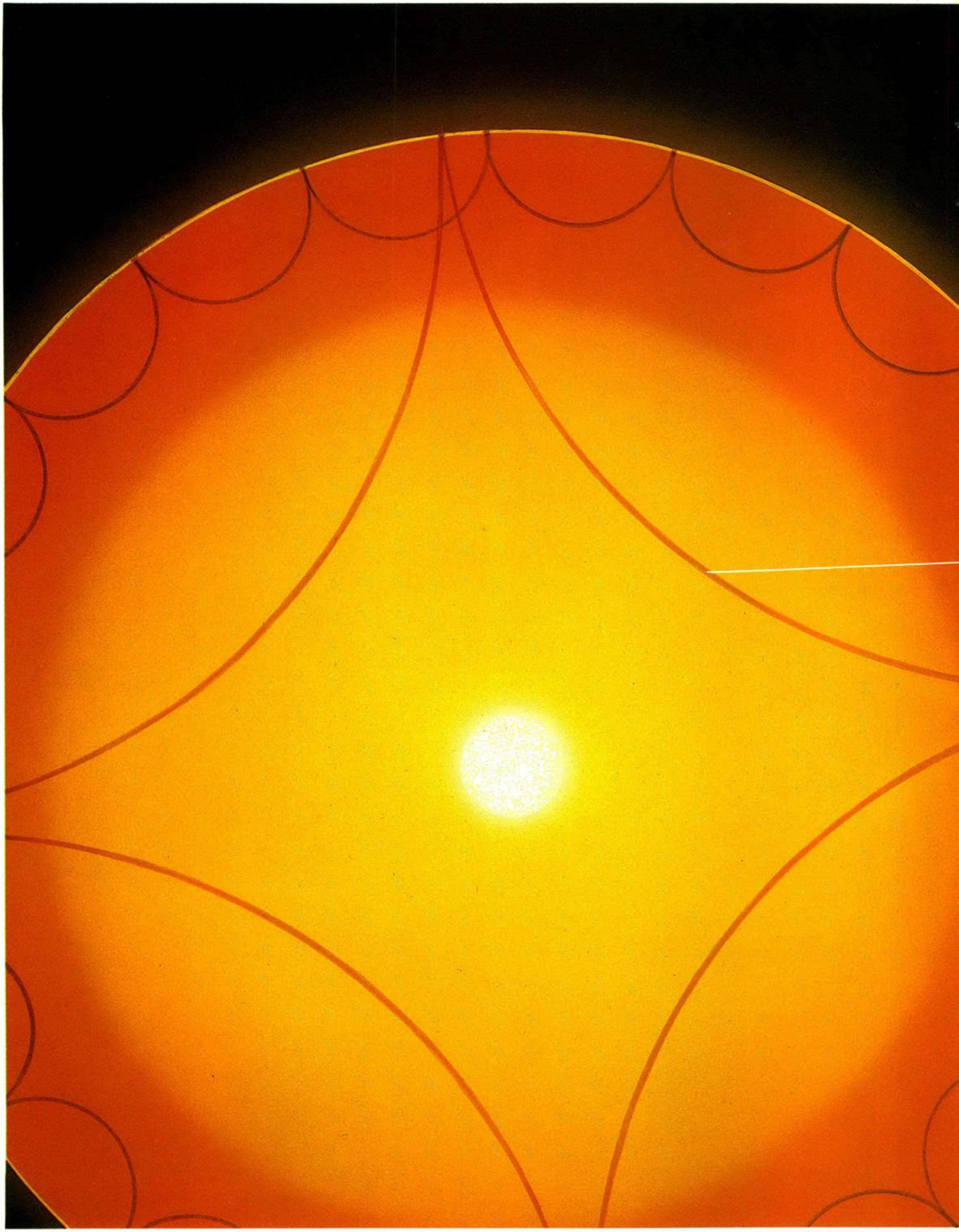
General relativity could neatly account for the observed Mercurian motion, but Dicke and his associates reasoned that a similar change would occur if the Sun were not perfectly spherical but slightly fatter through the middle because of rotation. (For this same reason the equatorial diameter of the Earth is about 23 miles larger than its polar diameter.) After all, they reasoned, the Sun is a rotating gaseous sphere. It *ought* to have some oblateness.

Their first measurements indicated a very slight bulge that would cause Mercury's orbit to precess by an amount similar to that observed, which would thus make general relativity dispensable. Provoked by the measurement and its implications, many other astronomers tried independently to confirm Dicke's oblateness measures — and failed. As it stands today, the Sun seems

# Inside the 'New' Sun

Helioseismology's new Sun has a smaller core and a deeper convective region.


Core
(where nuclear reactions run
and neutrinos come from)
Temperature = 15 million kelvins
Radiative Region
Convective Region
Photosphere
Corona



to have no measurable oblateness and general relativity remains intact.

But apart from relativity, a real oblateness (if found) would also have implications for models of solar structure. Oblateness would have told astronomers that the inner core of the Sun was rotating rapidly. "No oblateness" therefore was a negative result that actually pinned down an important constraint for models of the Sun's interior.

### Is the Sun Really a Nuclear Reactor?

This isn't as foolish a question as it sounds. Some recent measurements of the Sun's diameter show that it is contracting, something protostars do as they heat up to become full-fledged stars. This is a stage of life that the Sun should have completed about 4.6 billion years ago — if our solar models are correct. On the other hand, if the Sun turns out to be still contracting, then every solar model (not to mention much of solar physics) should be thrown out the window. A contracting Sun is one that needs no nuclear-reaction energy to keep shining, and this is utterly in conflict with our present understanding. But the models are far from perfect and no astronomer can afford to overlook the possibility that they've been off-track right from step one.

Here's the evidence. Astronomers at the Royal Greenwich Observatory have been timing the interval between the passage of the east and west edges of the Sun through the observatory's meridian every clear day since 1836. Solar astronomer John Eddy studied the observatory's records and detected a long-term decrease. His results showed that the Sun's diameter was shrinking at a rate of 2.25 arcseconds per century in the equatorial diameter.

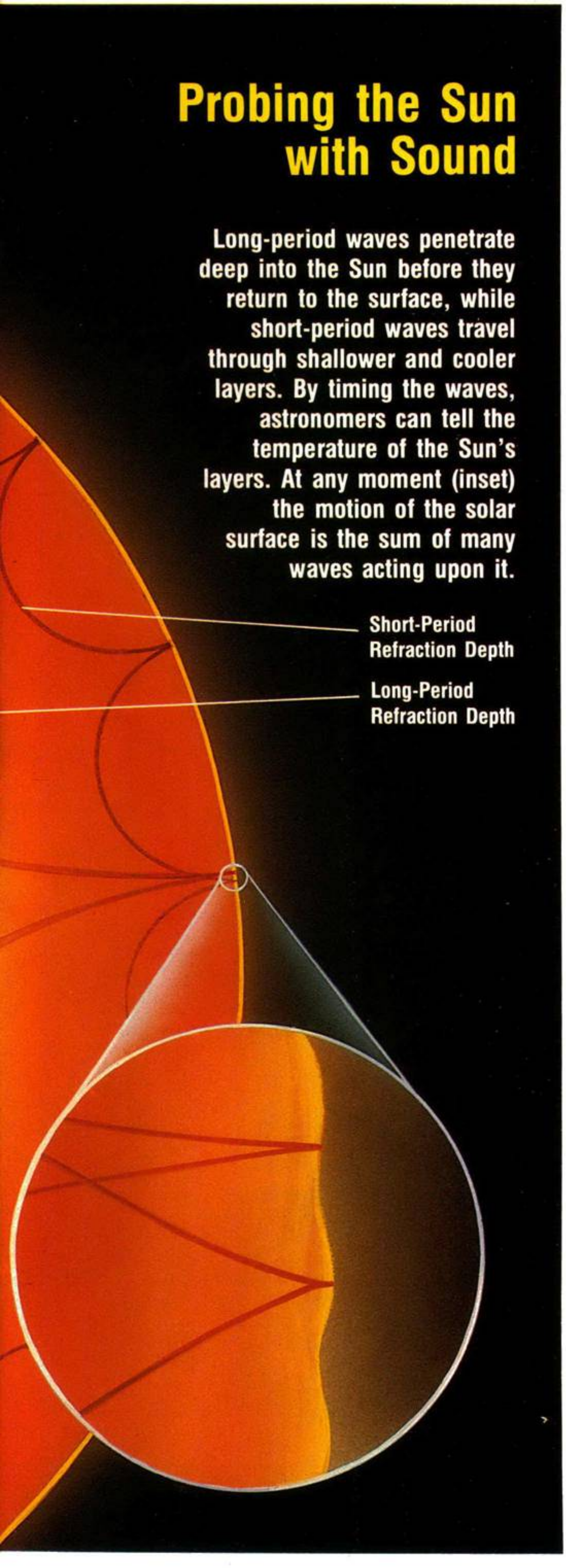
I. I. Shapiro of MIT then examined twenty-three historical transits of Mercury across the disk of the Sun. Because Mercury's orbit and period are well known, transit timings can be used to determine the solar diameter. Shapiro's results indicated a shrinking of no more than 0.3 arcsecond per century and, given the margin of error in the measurements, he could just as well say the Sun was not shrinking at all.

Next, researchers at the U.S. Naval Observatory attempted to measure the solar diameter during total solar eclipses. Alan Fiala of the Nautical Almanac Division of the observatory repeated an experiment carried out at most eclipses going back a century or more. His measurements indicated that the solar diameter was indeed a bit smaller now than similar measurements made in past eclipses showed it to be.

To double-check what seemed like an unbelievable result, Fiala, together with Sabatino Sophia and John O'Keefe of NASA's Goddard Space Flight Center, looked further into past records of solar eclipse and transit measurements. These measurements were reanalysed very carefully and the result, again, indicated that the Sun was larger about a century ago than it appears to be today.

Finally Timothy Brown, a solar physicist at the High Altitude Observatory in Boulder, Colorado, decided that the solar contraction problem had to be settled once and for all. He built a special telescope to repeatedly and *impersonally* measure the solar diameter as the Sun crossed the meridian — day after day for months and years at a time. Using several years worth of measurements, his statistical analysis (which is widely accepted) showed no evidence at all for a solar contraction.

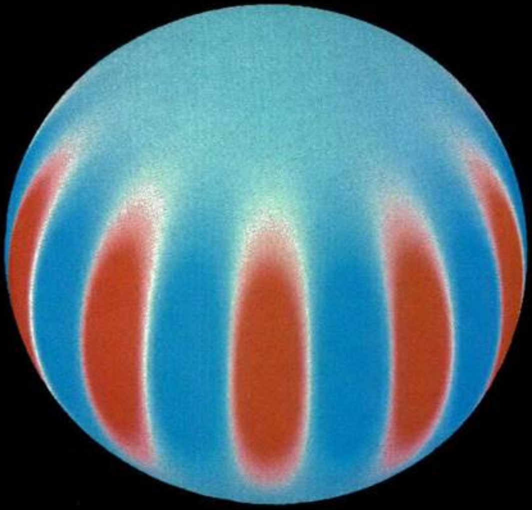
## Probing the Sun with Sound



**Long-period waves penetrate deep into the Sun before they return to the surface, while short-period waves travel through shallower and cooler layers. By timing the waves, astronomers can tell the temperature of the Sun's layers. At any moment (inset) the motion of the solar surface is the sum of many waves acting upon it.**

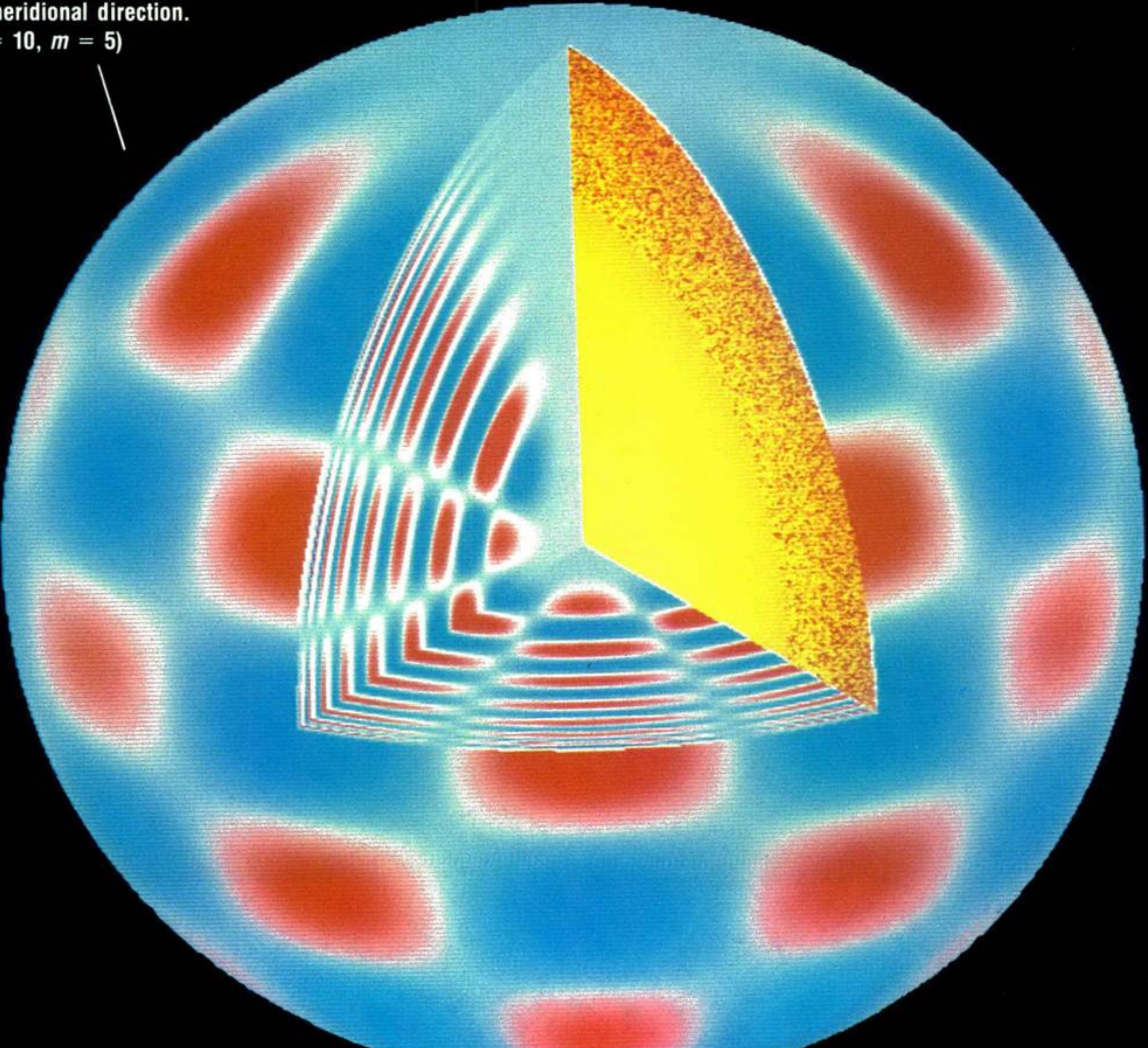
# Computer Suns

**The neat, simple patterns of solar vibrations modeled by computer are helping astronomers understand the far more complex motions of the real Sun. In the models, blue regions are rising toward us and red are sinking. The big model has been cut away to show how the vibrations resonate deep into the Sun.**



Ten standing waves, all in a meridional direction.
($l = 10$, $m = 10$)

Ten standing waves, five in a meridional direction.
($l = 10$, $m = 5$)



What had gone wrong? The answer seems to be that previous studies combined measurements carried out by many different observers at different times using different instruments. In principle the measurements should have had comparable accuracies, but somehow the older observations always overestimated the solar diameter. This naturally led to a rapidly shrinking Sun. And because the models weren't thoroughly reliable, even such an outrageous idea as this had to be taken seriously.

These case studies highlight something noteworthy. Each one reflects the fact that our models for the Sun's structure are weak and flawed. To an embarrassing degree, astronomers simply have no solid understanding of even very important physical facts about the Sun. When solar observation butts its head against solar theory — and neither observation nor theory compels total confidence — what is to be done? Again and again in recent years astronomers have returned to one big question: What is the inside of the Sun like?

### The Sun Has the Shakes

Thanks to helioseismology, it now appears that answers to many questions regarding solar structure are within reach. Studying and interpreting the way the solar surface quivers and shakes will, by a combination of observation and computer calculation, lay bare the Sun's interior temperature, density, and chemical composition, as well as its internal rotation. These properties are the essential building blocks for any theoretical model powerful enough to be useful.

In a sense, helioseismology began even before astronomers knew of it. Long before the neutrino controversy erupted, solar astronomers had discovered that the Sun's surface oscillated. In 1960 they noted that small portions of the Sun's photosphere rose and fell every 5 minutes with speeds of about 20 feet a minute. They thought this was caused by turbulent motions at the solar surface, because these also changed on about the same time scale, and the up-and-down oscillations grew strong and died away in groups of waves, as if driven by a turbulence that varied in strength. A decade later, however, several researchers realized that the up-and-down motions came from sound waves within the Sun striking the surface and rebounding back down into the solar interior. Also, under close examination the 5-minute period broke down as the startled astronomers discovered that they were seeing *hundreds* of different periods, ranging from about 3 minutes to 3 hours, all going on at once and superimposed on one another in a pattern that only *seemed* random.

The conclusion was stunning: The entire Sun was ringing with sound waves like a huge gong. Driven by heat from inside, the solar gas is emitting a tremendous roar that has set the entire Sun vibrating.

What makes a "ringing Sun" so exciting is that the oscillations carry information about the deep solar interior. Like a resonating gong, the Sun's shape constantly undergoes tiny, patterned distortions of a rhythmic nature. These distortions are in effect three-dimensional waves that rise out of the deep interior of the Sun and can also move about its circumference. The disturbances that produce and maintain these oscillations originate at all levels within the Sun, from just beneath the surface to far down in the interior. The observable properties of the oscillations — their timing and strength — depend upon the environment they pass through on their way to the surface. But inverting the apparently chaotic motions of the surface to yield information about the Sun's interior is not an easy task. It demands sophisticated mathematics coupled to ample resources of computer power and a vast database of solar-oscillation observations, as yet uncollected.

### Solar Physics in a Bathtub

Let's pick up one typical wave as it bounces from the underside of the surface and follow it as it descends back into the Sun. Diving deeper, the wave moves through ever hotter layers of gas. As the gas grows hotter, the local speed of sound and therefore the local velocity of the wave also increase. Because the wave is not propagating precisely vertically, at any given point some part of it will be at a depth lower than the rest. But under these conditions, lower equals faster, and so the lower parts of the wave front pull ahead of the shallower parts.

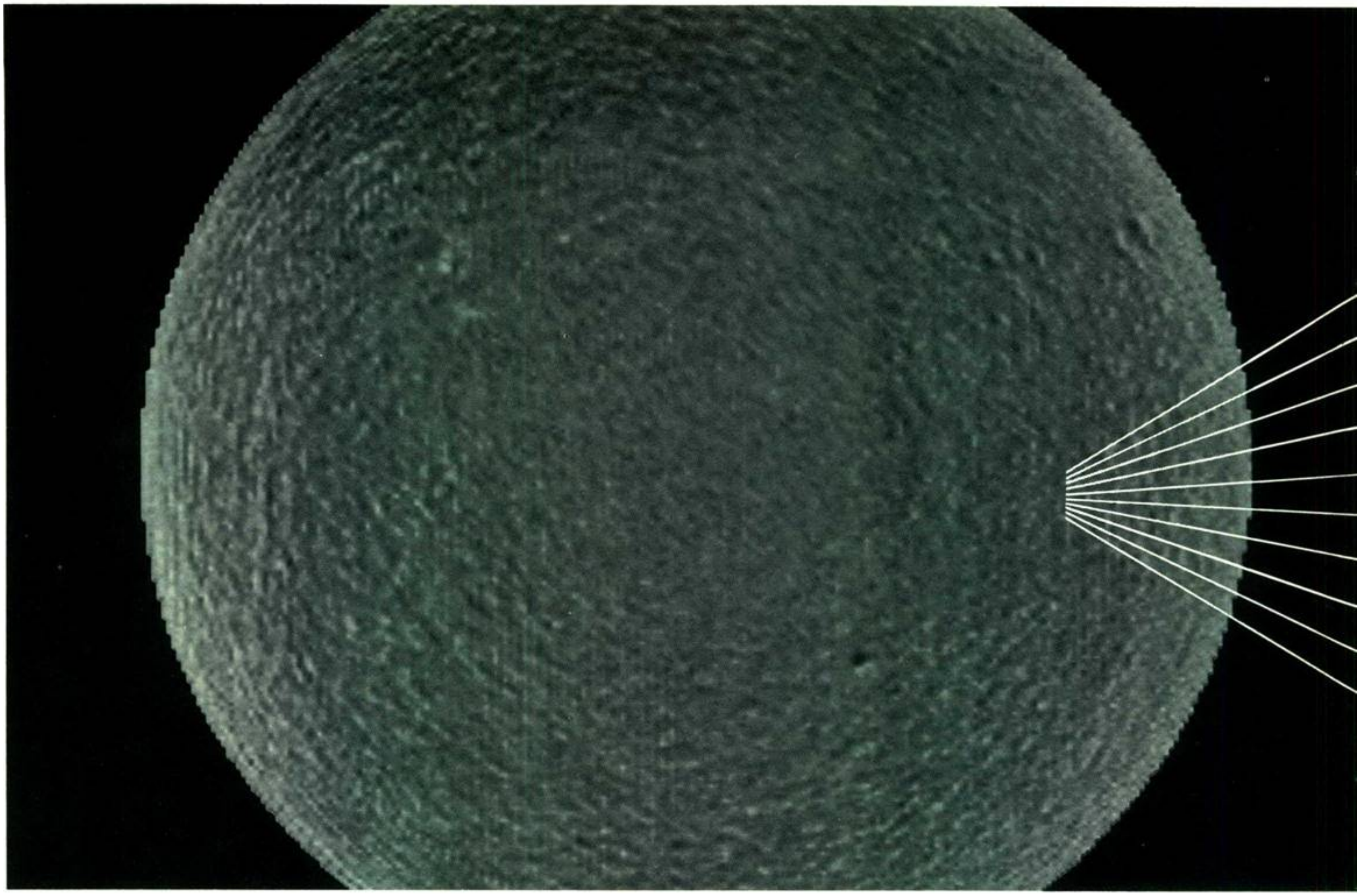
**The Sun's quivers and shakes are helping astronomers probe the solar interior, just as geophysicists study the Earth with earthquakes.**

The net result is that the direction of motion for the wave bends more and more toward the horizontal. At some "refraction depth" it bottoms out and turns back toward the surface. At the solar surface the abrupt drop in density to the near-vacuum of space creates an uncrossable boundary for the wave that reflects it downward again, just as light reflects from a mirror. The process occurs over and over, resulting in waves that carve semicircular paths through the Sun as they repeatedly bounce and refract their way around the solar circumference.

How deep it penetrates and how far around the Sun the wave goes before it hits the surface depend on its wavelength. Some waves have just the right length to make an integer (exact) number of bounces before they end up where they begin. Astronomers characterize these waves by the number of times they rebound in one complete circuit of the Sun. For instance, a sound wave that bounces twice before returning to its origin is designated as $l = 3$ because it touches the solar surface in a total of three places. An $l = 6$ wave makes five bounces before it comes back to the starting point, and so on for higher and higher numbers.

Physicists have a phrase for oscillations that make an integer number of vibrations in a body: harmonic resonance. You can see an everyday example if you fill the bathtub about half full and swish the water around. If you swish it randomly and fast, the water develops a confused chop of small waves. But as you agitate less often and more rhythmically, the waves become fewer and larger. For every bathtub there's a special "jackpot" frequency called the *fundamental mode*. Find it and the water moves all at once in a single wave.

After you wipe up, refill the tub to the same level and try agitating exactly twice as fast as the fundamental mode. Notice now that the waves are smaller and



always occur in the same places. These are called *standing waves*; the locations between them where the surface is at rest are called *nodes*. (Don't confuse "node" with "mode.") Standing waves will always emerge when the frequency at which you agitate is a perfect fraction (2/3, 1/2, 1/3, 1/4, and so on) of the fundamental mode; any such shorter frequency that produces a standing wave is called an *overtone*. Now for the fun of it — you're already wet — try to find the tub's other overtones. How high do they go?

The interior of the Sun is ringing with a virtually endless number of modes and overtones. These modes, at a variety of wavelengths and speeds, can lead to some waves penetrating deeply into the Sun, circumnavigating after only a few reflections from the surface. For example, waves with low *l* numbers penetrate to great depths and tell us about the physical conditions there; higher *l*-number waves make shallower dives and explore the Sun's upper layers. Each *l* wave resonates in a cavity or shell; its upper bound is the solar surface and its lower bound is its refraction depth. The practical limit for observing solar waves is about $l = 300$, by which point the waves' looping paths are so small and shallow that they are significantly affected by the turbulence — the visible granulation — of the solar surface.

### Making the Sun Shake

What in the solar interior sets the oscillations in motion? How do they move through the Sun? Virtually any disturbance or internal motion can start oscillations going. We know the outer third of the Sun is convective: like a pot of water on the stove, it "boils" as heat is supplied from below. Convection is essentially hot bubbles of gas rising and cooling. The bubbles capture heat coming from the interior and pass it on to the higher and cooler layers. As the bubbles rise, their motion disturbs the gas they flow through and starts it oscillating.

In a structure like the Sun two kinds of oscillation can occur. The first is the sound-wave kind, driven by changes in pressure. The sound waves are alternate compressions and rarefactions that move through the gas at the speed of sound. In astronomers' shorthand, waves of this type are referred to as p-waves or p-modes.

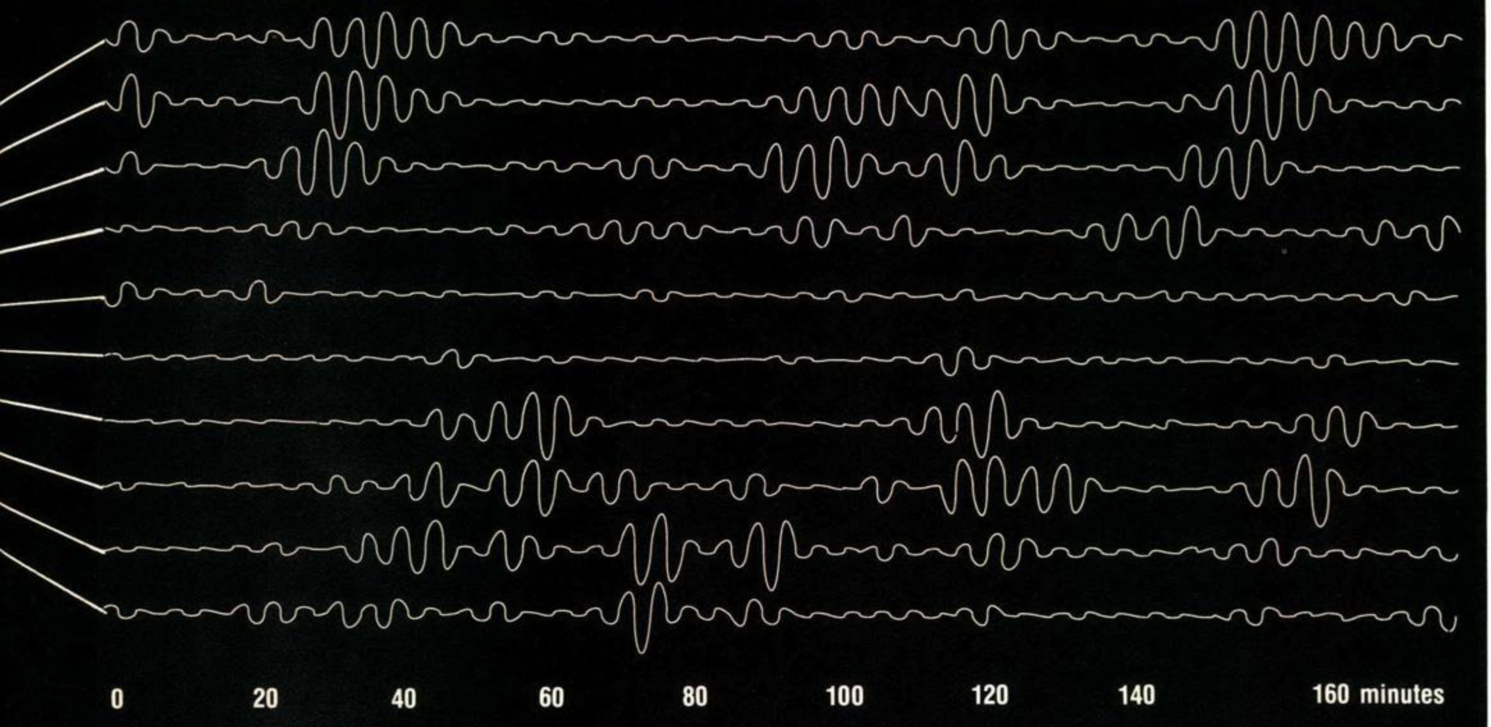
The second type of oscillation is the so-called gravity, or g-wave type. (These are totally unrelated to the gravity waves predicted by general relativity.) Solar g-waves are created when gas is disturbed from its at-rest position and is then pulled back into place by gravity. The waves you made in the tub — or those that break on the seashore — are g-waves. This second type of wave can occur only where the pressure of the material varies with depth; in the case of the Sun, this means from the core up to the lower edge of the convective zone.

From the solar astronomer's standpoint, p-waves are relatively easy to observe. They have periods that range from 3 minutes to nearly an hour and propagate through the outer two thirds of the Sun. G-waves, however, being denizens of the deep interior only, have periods of 40 minutes or longer, low amplitudes, and so far have been detected only weakly. A much larger database of observations will be needed before studies of g-waves can contribute significantly to our understanding of the Sun.

Convection creates wave disturbances with many

## Order beneath the Chaos?

**As solar vibrations continually reinforce and cancel one another, the Sun's surface heaves and falls with a roller coaster motion. Dark regions in the photo are receding; light ones are approaching.**



different periods, but only those that fall into one of the resonant periods are reinforced and get "pumped," much as the harmonic motion of a child on a swing is pumped at regular intervals by a parent. When their period is exactly right, solar oscillations become standing waves, but these differ from those in the bathtub because the Sun's shape demands that they be spherical. And because the Sun is a three-dimensional object, the nodes where the surface is motionless become planes that slice inward. Some waves encompass the entire global structure of the Sun, while others dominate smaller portions and still others only localized regions. The picture of the real Sun's motions is fantastically complex. It is constantly changing from place to place and from moment to moment (see above).

To help them understand what is going on, astronomers have used computers to generate simplified models that depict a Sun resonating harmonically with only a few modes and overtones. In the models it is most convenient to set up vibrations parallel to the equator and axis of the Sun, although other orientations are possible in reality.

We have seen *l* used as an index of the number of waves in the Sun. Astronomers use another term, *m*, to indicate how many waves have nodes only in the meridional (longitudinal) direction and *n* to denote nodes in a radial direction. The model Suns on page 26 show different combinations of *l* and *m*, but even the most complex of the computer-created models is unfortunately still much simpler than the real Sun.

### GONGing Up on the Sun's Oscillations

The exciting possibility of using measurements of solar oscillations to probe the deep interior of the Sun has led to the development of the Global Oscillation Network Group, known as GONG for short. This worldwide project is directed from the National Solar Observatory in Tucson, Arizona, the solar division of the National Optical Astronomy Observatory.

The GONG program is aimed at achieving six specific goals. First, astronomers need to determine how the Sun's temperature, density, and composition vary from the core to the surface. These properties and values underpin everything else known about the Sun. Second, astronomers want to measure the internal dynamics of the Sun and in particular the rotation of the deep interior. This might give us an idea of how the solar dynamo works, so we can understand the 11- and 22-year cycles of solar magnetic activity.

Third, astronomers need to determine the initial helium abundance in the solar nebula, which has direct links with studies of the planetary system and stellar evolution. Fourth, astronomers need to measure the interior solar oblateness (if any), which constrains the models and provides a further test of general relativity. Fifth, any good solar model built from the new data is going to have to explain the neutrinos — why Davis' experiment is detecting fewer neutrinos than calculations predict. And last, astronomers hope to explore mechanisms by which solar oscillations could heat the chromosphere and corona. (The photosphere has a temperature of 6,000 kelvins while the corona just above is at 2 million kelvins. One solution to this long-standing puzzle is that some energy from oscillations is leaking past the surface and buffeting the coronal gas with sound waves, thereby heating it.)

The GONG project will station six automated 50mm refractor telescopes at locations around the globe. This assures that at least two instruments will be looking at the Sun all the time. To amass the required database of observations, the telescopes will image the Sun once a minute, around the clock, for three years. The observations have to run continuously because gaps from nighttime, cloudy weather, or instrument failure introduce spurious signals into the record. These look similar to effects induced by real solar oscillations.

The reason for such a lengthy period of data collection is that when astronomers wish to discriminate between any two motions with periods that differ by only one part in a million, they need to follow both motions for a long time before they drift out of phase with each other. Multiply this by all the ways the Sun can oscillate and it becomes clear why astronomers will need an immense amount of data to track all the individual waves coursing through the Sun and then turn *that* into information about the Sun's interior. In round numbers the GONG network will generate more than a gigabyte of data per day, every day, for three years.

**Making new models of the Sun's interior means taking one picture a minute, every minute, for three years.**

One oscillation can be distinguished from the next by its amplitude, strength and frequency, and the timing of each wave crest as it arrives at the solar surface. Because the waves manifest themselves as up-and-down motions of the solar surface, they can be detected using the Doppler principle. When a wave rebounds from the surface, the photosphere heaves upward toward us, introducing a small blue shift in its spectrum. Similarly a wave diving back into the interior lets the surface fall and introduces a red shift. As waves propagate around the circumference of the Sun, the atmospheric gases heave up and down in a roller-coaster pattern. The pattern is only apparently random: actually the motion of any part of the surface at a given moment is the sum of all the standing waves acting upon it right then.

Another important property of the waves is spatial coherence, that is, how much of the solar surface is taking part in the heaving motion. The degree of coherency varies greatly. Some waves are global in extent; others are generated only in local areas — down to as small as the size of the photosphere granules.

The GONG project's telescopes are each equipped *with an instrument* called a Fourier tachometer. This is capable of measuring extremely small Doppler shifts (one part in a billion) at more than 65,000 points on the Sun. At the core of the tachometer is a small Michelson interferometer, a device that splits the light into two right-angle paths, rejoins them, and then measures the minute spectral shifts as they interfere with each other. From these changes astronomers can build a detailed picture of the solar disk that shows areas moving toward us and away.

### A 'New' Sun Is Dawning

While the GONG project won't get going in earnest until the early 1990s — potential telescope sites are being tested at present — its techniques have been tried out using observations made during the Antarctic summer, when the Sun is visible for several days at a time. The results of these trial runs at the South Pole and at other observatories have already begun to alter our view of the Sun.

One area of interest concerns solar rotation, which has a bearing on many other problems too. Preliminary results now indicate that the inner rotation of the Sun may be similar to the surface rotation; this means the interior would rotate slowly. If the Sun lacks a rapidly rotating core, this is good news for general relativity, but it does take away one possible solution to the neutrino problem. Regarding the latter, studies of the oscillating waves find patterns that are consistent with a deep solar interior temperature of about 15 million kelvins, thus ruling out the "cool core" solution.

Rotation also impinges on the sunspot cycle, the well-known periodic change in the number of sunspots observed on the Sun. Spot numbers reach maxima about every 11 years, but their magnetic polarities change with every other cycle, or approximately every 22 years. Sunspots are caused by changes in the magnetic fields of the solar atmosphere and interior. All solar activity, including sunspots, erupts most vigorously where these magnetic fields are strongest. Astronomers have discovered a definite link between the rotation of the Sun and the production of these magnetic fields. Astronomers suspect that other aspects of the Sun change in phase with the solar cycle. For instance, the speed and exact character of the Sun's rotation may be influenced in some way by the cycle. However, evidence for a correlation between the cycle and the rotation rate is indirect and very difficult to prove.

Last year it became clear that the Sun grows in brightness right in step with the sunspot cycle as it creeps toward maximum. (See "The Rise and Fall of the Sun's Activity" by Jeff Kanipe, Richard Talcott, and Robert Burnham, October 1988.) These variations are important because of their possible link with changes in the Earth's climate, both short-term and long. In turn, solar astronomers are hopeful and excited that their studies of solar oscillations may provide clues and information about the workings of the solar cycle.

The GONG project in some ways is a new departure for solar physics. No other solar research project has ever attempted to collect and master such an enormous amount of data. While the instruments are relatively simple and lack the sheer bulk of the big solar telescopes at Kitt Peak and Sacramento Peak, this global network of 2-inch telescopes promises to yield our first real pictures of the solar interior. A revolution in solar astronomy lies just ahead. □

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*James Charles LoPresto is a solar researcher and professor of astronomy at Edinboro University in Pennsylvania. His most recent article for ASTRONOMY was "The Geometry of Space and Time," published in the October 1987 issue.*

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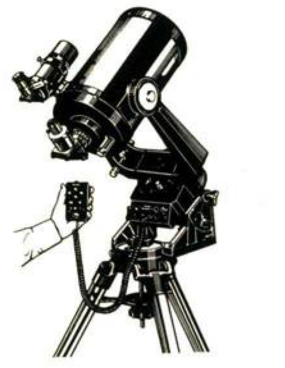

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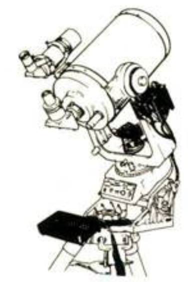

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# A New Window on Star Birth

### The new science of submillimeter astronomy promises to penetrate the clouds surrounding newborn stars.

by Karen Hartley

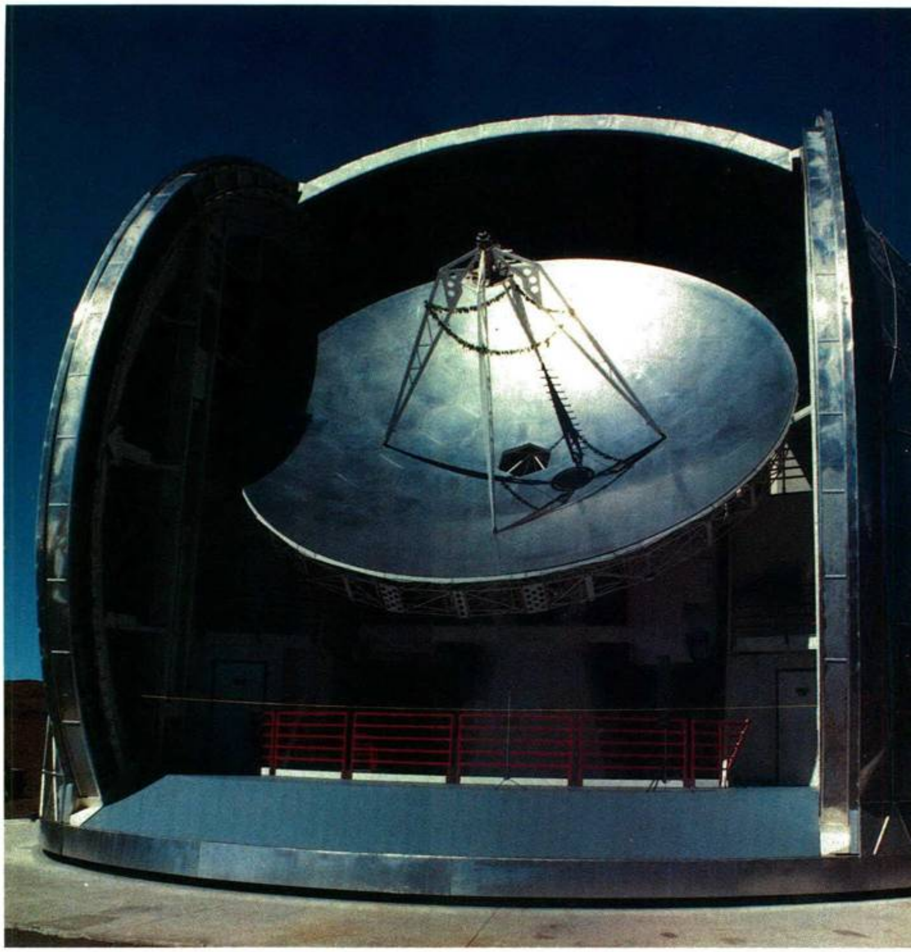
Astronomers covet radiation from across the electromagnetic spectrum. Celestial objects at different temperatures emit radiation at different wavelengths, so each wavelength band provides a unique view of the universe. Only by observing radiation of all wavelengths can astronomers get a complete picture of astronomical objects.

Some objects, such as stars that have recently exploded, are fiery hot and emit gamma and x-rays. Other objects, such as our Sun and similar-sized stars, are much cooler and emit ultraviolet and visible radiation. Still others, such as giant clouds of gas and dust, are some of the coolest objects in the universe and can be seen only with infrared and radio telescopes.

There is one prominent region of the spectrum that is just beginning to be explored, however. That is the region located between infrared and radio radiation — the submillimeter. This radiation arises from relatively cool objects and in particular from the large clouds of gas and dust where stars form. Because of this, observations at submillimeter wavelengths have the potential to revolutionize our understanding of the star-formation process.

## Observing the Submillimeter

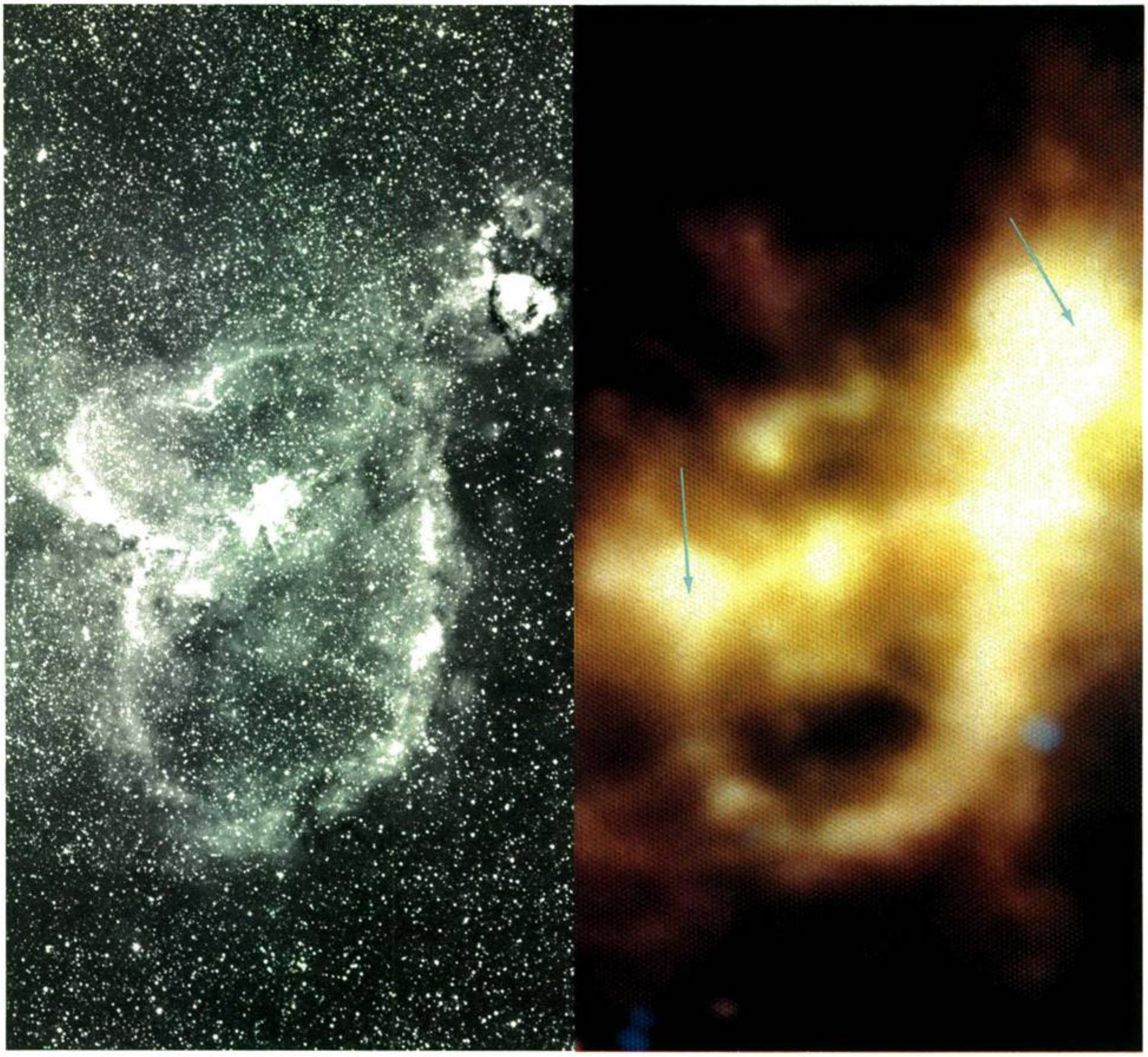
If your eyes were sensitive only to submillimeter wavelengths, the sky would appear to be made up mostly of patchy areas of nebulosity. But you would see only a small fraction of all the submillimeter radiation from space because water vapor in Earth's atmosphere absorbs much of this radiation. Only about 25 percent of the submillimeter waves coming from space ever reach the telescopes used to collect them, which is why submillimeter telescopes must be located at some of the highest and driest sites in the world.



**PEERING INTO THE UNKNOWN,** the dish of the Caltech Submillimeter Observatory (above) collects submillimeter radio radiation. Such telescopes will penetrate star-forming regions (right) and promise new insights into how stars form.

Atmospheric absorption is just one reason submillimeter astronomy has begun only recently. Because submillimeter wavelengths are fairly long, they have a low energy, and thus submillimeter telescopes must have the large diameters of some radio telescopes to collect a sufficient amount of energy. But at the same time submillimeter wavelengths are short enough that submillimeter telescopes must have extremely accurate surfaces approaching those found in optical telescopes. As Philip Myers of the Smithsonian Astrophysical Observatory (SAO) explains: "Because it's difficult to observe the submillimeter from the ground, people have used other wavelengths first."

The necessary technology eluded scientists for years, which confined submillimeter observations to tele-



**STARS ARE BORN** in the cool interiors of dust clouds, where they radiate strongly at submillimeter wavelengths. The slightly warmer exteriors of dust clouds in the star-forming region IC 1805 shine brightly at infrared wavelengths (right) and are particularly strong in two areas (arrows). The hot gas surrounding the dust clouds glows most strongly in visible light (left).

scopes not specifically built for that purpose. But the needed precision and size were successfully married in 1986 in two instruments built on top of Hawaii's 4,200-meter-high Mauna Kea mountain: a 10.4-meter-diameter dish, operated by the California Institute of Technology, and the 15-meter-diameter James Clerk Maxwell telescope, a British-Dutch-Canadian venture.

Outside the United States, Sweden and the European Southern Observatory recently completed a 15-meter telescope at La Silla, Chile, the only true submillimeter instrument in the Southern Hemisphere. And a 3-meter telescope operated by the University of Cologne has been moved recently to a site higher in the Swiss Alps so it could operate in the submillimeter range.

A 10-meter submillimeter telescope funded by the University of Arizona and the Max Planck Institute for Radio Astronomy in West Germany is also in the works. The institutions will build the instrument on Mount Graham in Arizona. Congressional and presidential approval late last year clears the way for developing Mount Graham, and scientists are hoping to start construction later this year.

If these new telescopes live up to expectations, astronomers will get an unprecedented view of how stars form. This in turn may shed light on how life began. The stuff life is made of — carbon, nitrogen, and oxygen — is a product of the evolution of many generations of stars. As each generation dies, it ejects more of these heavy elements into space. Though a great deal is known about star death, star birth has been shrouded behind a veil of dust and gas. Submillimeter telescopes will give astronomers the tools they need to penetrate that veil.

### The Birth of a Star

Stars are born in vast complexes of gas and dust called giant molecular clouds. Although astronomers know in broad outline that these clouds contract under the influence of gravity, fragment into smaller clouds, and continue collapsing to form stars, they know very few specifics about what occurs. The process is a fundamental mystery that astronomers desperately want to solve. (See "The Difficult Births of Sunlike Stars" by Steven Stahler and Neil Comins, September 1988.)

The first step is to measure the radiation coming from within these molecular clouds. Of the approximately five thousand such clouds in our Galaxy, one of the best studied is *the Orion Molecular Cloud.* Located in the sword of the constellation Orion, it can be seen on a clear night from the Northern Hemisphere with binoculars. But what you see in visible light is only a fraction of the cloud; most of its radiation is in the invisible infrared, submillimeter, and millimeter wavelengths. "All the action takes place behind this opaque cloud," Myers said. "At visible wavelengths, we can't see all the good stuff that's going on inside."

The amount of matter and pressure inside giant molecular clouds indicates that they should be producing new stars at a rate ten times what we can see being formed. It's as though the clouds are pregnant but not delivering. To make matters worse, when they do deliver, they don't do it at all consistently. Some of the older clouds bore children in clumps of 100,000, while other clouds had 300 at a time and still others had only 10 or 15 apiece.

It appears that something must be stopping these clouds from delivering new stars. Many astronomers believe that something is a magnetic field and that without the pressure supplied by the magnetic field, all the matter would collapse under gravity's pull. For stars to form then, some energetic force must compress the magnetic field enough to cause it to give way. When this happens, gravity takes over and the cloud begins to collapse.

Another mystery is how exactly the cloud collapses. Theoretically a nonrotating spherical cloud contracts equally from all sides to form a star. The cloud starts off large and cold, and thus there is little outward pressure to stop the object's contraction. But as the cloud collapses into a tighter ball, its temperature increases until eventually the thermal pressure is enough to counteract gravity.

In the much more likely event that the cloud rotates, it would collapse into a disk, similar to the way water circles a bathtub drain before disappearing. This disk would then contract further to form stars. Either the spherical cloud or the disk could also fragment and form stars.

### Clues to the Mystery

Because there's been no way to see what actually goes on inside a molecular cloud, star-formation theories continue to proliferate. And though submillimeter telescopes can penetrate these clouds, just seeing submillimeter radiation isn't enough. Astronomers have to look for the subtleties of a mystery to solve it.

There are two ways to search for these subtleties. The first is by studying the shifts in each molecule's distinct chemical signature, the spectral lines. The small shifts in these lines show how the cloud is collapsing. Another way to look for clues is to study the continuum radiation — the entire spectrum of radiation emitted by an object — coming from the cloud, which can show how hot and dense the region is.

Philip Myers and colleague Priscilla Benson first took on the case of star birth when they observed about 150 spots located in long, filamentary clouds with the 120-foot-diameter Haystack radio telescope in Westford, Massachusetts. Using the spectral lines of the ammonia molecule, which is a tracer of dense interstellar gas, they found some surprising results: the clouds weren't exactly uniform but rather had some spots that were more dense than others. This gave the clouds the appearance of "pearls on a string," Myers said. These pearls could be forming along the magnetic field lines thought to exist in molecular clouds. By studying the gas in thirty of the spots, they concluded that the pearls were likely to produce low-mass stars, those with masses near the mass of the Sun.

**If submillimeter telescopes meet expectations, astronomers will get an unprecedented view of star formation.**

The next question was, where do these low-mass objects fit in. Were they forming in isolation or were they part of a larger process? According to the model of "sequential star formation," when the first stars in a cloud are born, they help cause the cloud to collapse elsewhere and bear other stars. This happens when a sufficiently luminous star forms and subsequently heats the surrounding gas, which causes the gas to expand. The expanding gas in turn compresses the surrounding cold cloud, which causes it to collapse and form more stars.

The answer came in 1983, when the *Infrared Astronomical Satellite* confirmed that the cores Myers and Benson studied do make stars, but the data provided no evidence that these stars help to make others. Some low-mass star formation, it seemed, is a more solitary process than massive-star formation.

By this time Myers was hooked on star formation. He and collaborators Ned Ladd and Jacqueline Davidson are now studying star birth in two nearby clouds: the Taurus and Ophiuchus regions. Although not as carefully studied as the Orion Cloud, these regions are easier to see in detail because they are about a third of the distance of Orion. Using NASA's 3-meter Infrared Telescope Facility on Mauna Kea, which can also measure some submillimeter waves, Myers is looking at the continuum radiation emanating from the dust around the newborn stars in these regions.

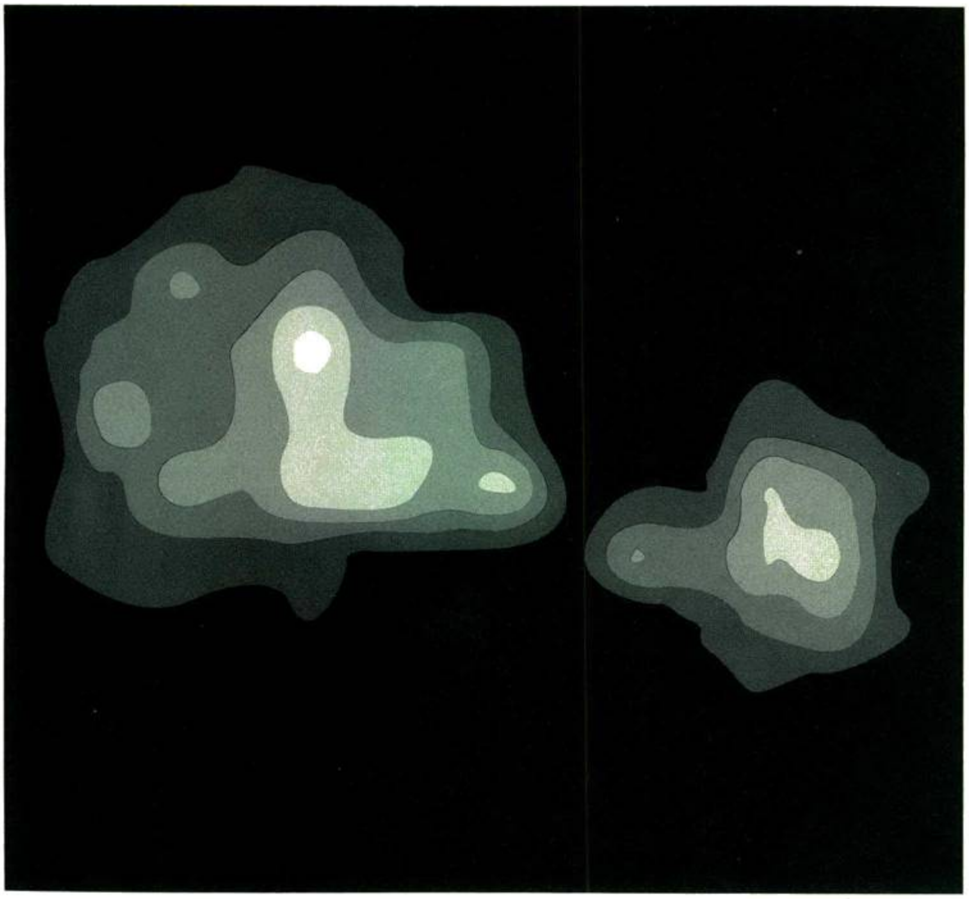
Myers isn't the only detective who has taken on the case of how stars form. Using the new 10.4-meter submillimeter telescope on Mauna Kea, Tom Phillips of Caltech is searching another galaxy for signs of star formation. Phillips, director of the Caltech Submillimeter Observatory, recently trained the telescope on Centaurus A, a nearby elliptical galaxy best known for a wide, dark streak of dust draped across its middle. Most ellipticals — galaxies that represent some of the most ancient objects in the universe — are made of millions or billions of old stars, yet a dust lane implies the existence of active star formation. A dust lane in this type of galaxy suggests stellar birth among a generation of senior citizens.

Phillips and his colleagues found the spectral signature of carbon monoxide — a molecule present in small amounts in star-forming regions, but one that emits strongly at submillimeter wavelengths — in Centaurus A. "It is unusual," Phillips says, "but undoubtedly there is star formation going on in there." This finding supports the suggestion that the Centaurus A dust lane is a remnant of a merger with a spiral galaxy, a type of galaxy usually associated with star birth.

### Getting a Better Look

Yet very little can be said with certainty. Finding a molecule is one thing, but tracing its movement and the movement of other objects inside a cloud is what will unravel the case. Although current submillimeter telescopes can do this, they have limited resolution. Their images are a kind of wide-field photographic record, but what astronomers need is a "telephoto lens" that can resolve fine details in these clouds. Astronomers can make such lenses by linking two or more telescopes with a method known as interferometry.

Interferometry takes advantage of the fact that resolution increases as the size of a telescope increases. Two or more telescopes observe the same object at the same time and the individual images are then combined by computer. The resulting image has the same resolution as would an image obtained by a single telescope having a diameter equal to the separation of the linked telescopes. This technique is used frequently with radio tele-



**SUBMILLIMETER EMISSIONS** reveal a disk of molecular material rotating around the Milky Way's center. This map shows both the approaching (right) and receding (left) parts of the disk. Astronomers hope to create images from such observations in the near future.

scopes, where large separations are needed to get high-resolution images. Until now, however, interferometry has been limited to radio and millimeter-wavelength telescopes.

But the Smithsonian Astrophysical Observatory wants to change that. The SAO has proposed the first submillimeter interferometer. By linking six 6-meter dishes together, the array would be able to see star-forming clouds at least ten times more clearly than existing single-dish telescopes. It would also bypass the problem of making one large, perfectly smooth single dish. Funds for a design study, which would detail the pros and cons of various sites and dish construction techniques, were awarded in October 1988. If funding is approved, it would be another six to seven years before the telescope could be built. Its completion, however, would open a new frontier for astronomical research.

Besides star formation, the array could study galaxy formation. Mapping the way carbon monoxide is distributed within galaxies will provide insight into the evolution and lifetime of molecular clouds. If these clouds are found outside spiral arms, it could mean that the clouds — and hence stars — form independently of the spiral structure. If the clouds lie within the spiral arms, it could mean these clouds form stars as a result of the same density waves thought to form the spiral arms. Studying the continuous emission from the dust in molecular clouds could reveal sites of star formation in galaxies other than our own.

The array will also observe quasars and the active nuclei of galaxies so astronomers can try to understand the most powerful objects in the universe. Astronomers know that these objects have immense amounts of energy packed into a small volume in their cores. How so much energy can be produced in such a small space has kept theoreticians busy for a couple of decades. Much of what we know about the subject comes from observations at radio wavelengths. However, the majority of quasars are "radio quiet" and astronomers think these objects may emit most of their radiation in the submillimeter.

Closer to home, the array will observe the atmospheres and surfaces of solar system objects as well as measure the subsurface temperatures of such objects as Mercury, Mars, and Saturn's rings. And the array should be able to measure the motions of winds and precipitation on Venus and Saturn's moon, Titan.

And then there's perhaps the most tantalizing revelation of all — the unexpected. Whenever a new wavelength has been breached, unanticipated discoveries have surfaced. The same is expected of the submillimeter. "It's not possible to predict exactly what will happen," Phillips says.

Although submillimeter astronomy is expected to find the unexpected and to fill voids in our understanding, whether it can reach its expected potential is unknown. Both of the Mauna Kea telescopes are new but only the Maxwell telescope is operating at its highest frequency. And only time will tell if these instruments will achieve their design goals. In addition, the devices that receive the submillimeter radiation have room for improvement. "Submillimeter wavelength receivers are still fairly new," Myers said. "There's still a lot of development that can be done."

In 1987 the SAO received funds to begin developing receiver instrumentation for their array. Even if the receiver technology is perfected, however, Myers said a more limiting factor is likely to be the emission from molecules, particularly water vapor, in Earth's atmosphere. "If there's too much of that extraneous emission, it really prevents us from doing the astronomy."

Charles Lada of the University of Arizona agrees. He believes that although some information will be obtained, the atmosphere is too much of a hindrance to achieve any striking results. "I think submillimeter astronomy's real future will be a long time from now when they put these telescopes into space," Lada says. Ground-based efforts, he believes, will serve to provide an avenue for honing the science of submillimeter work before sending an instrument into space. "It's important that the [ground-based] telescopes learn how to use the submillimeter best to be in a good position for space research."

But for the foreseeable future, submillimeter astronomy is rooted firmly to the ground. From mountaintop observatories rising above much of Earth's atmosphere, submillimeter telescopes are opening a new window on the universe. What astronomers will learn about the births of stars, galaxy formation, or quasars is anyone's guess, but the search, at least, has begun. ☐

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*Karen Hartley is a science journalist and editor of* The Quarterly Report, *a newsletter for the Massachusetts Institute of Technology's Sea Grant College Program.*

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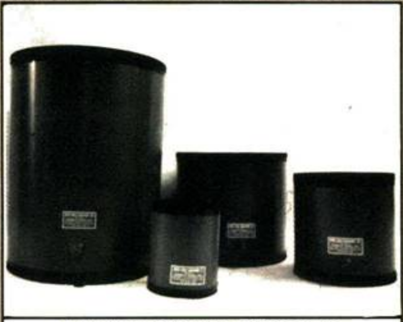

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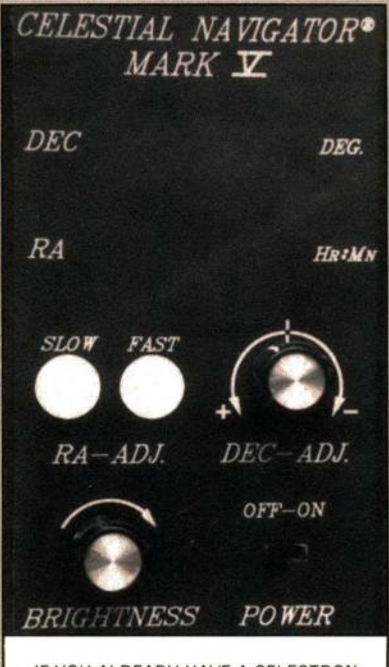

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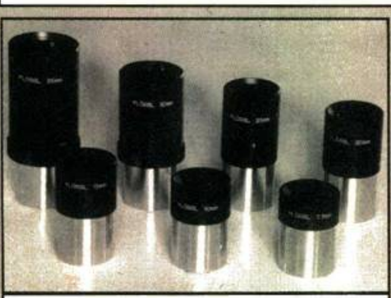

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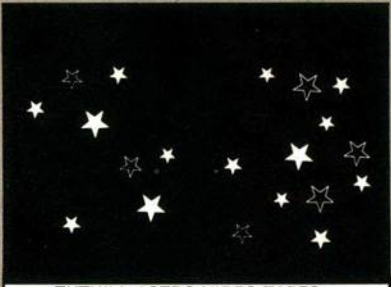

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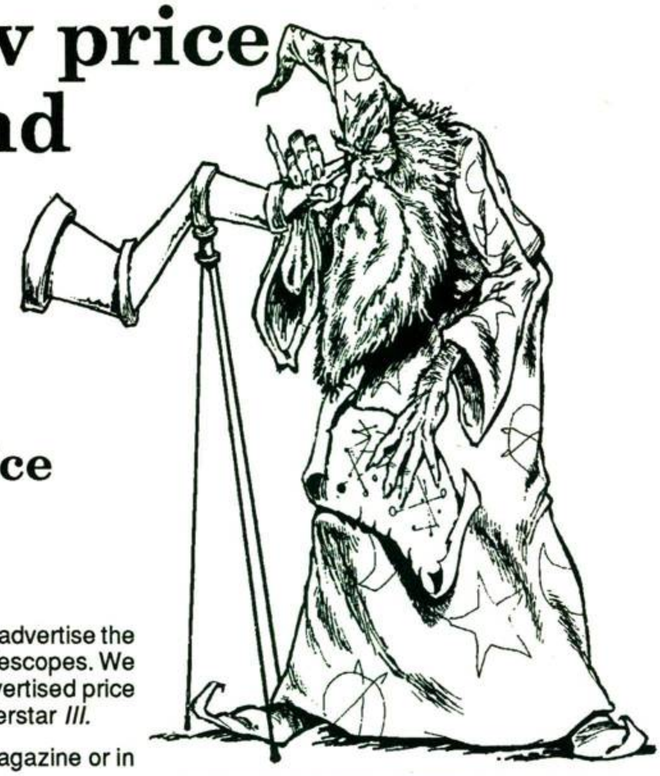

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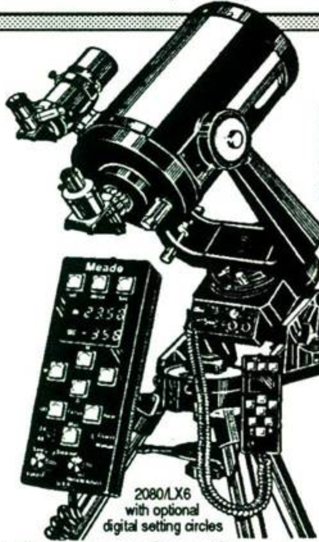

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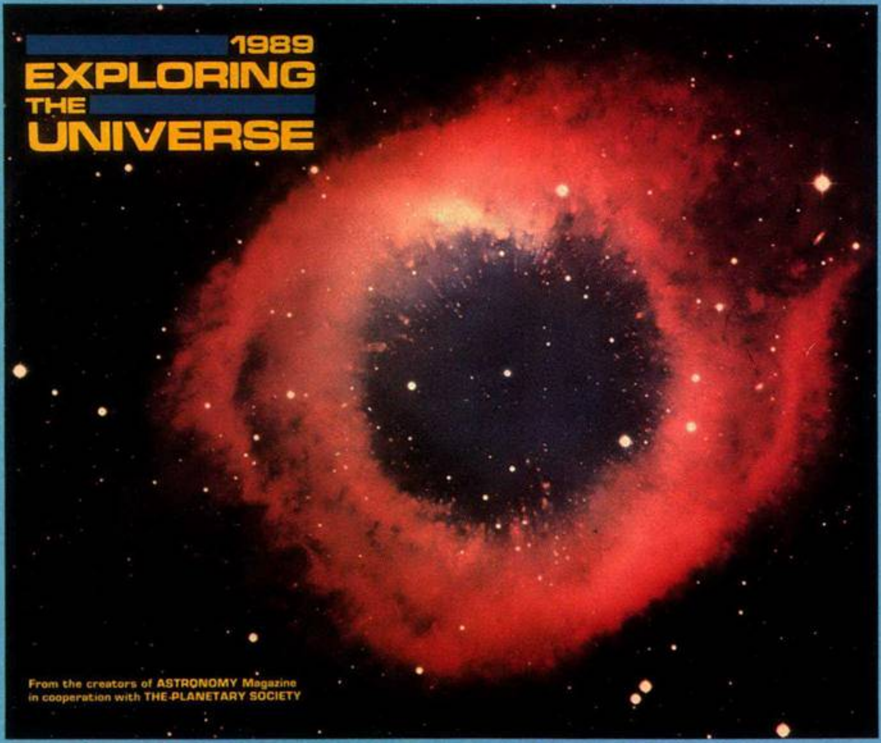
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RADIO ASTRONOMY

# The Curious Shapes of Cosmic Jets

Straight, curved, or tangled — jets are shaped by the intergalactic environment and the sources that drive them.

by Jeff Kanipe

One of the most dramatic examples of violence in the universe is the cosmic jet — a stream of hot gas literally squirted from the core of an active galaxy or quasar by a massive, compact object. Jets can range from thousands to millions of light-years in length, move at nearly the speed of light, and appear either singularly or, as most do, with a counterjet emerging from the opposite side of the core.

Jets also come in a variety of shapes. Some jets stick straight out of the core like a straw, but quite a number of them are bent or curved. For over a decade astrophysicists have tried to learn why some jets are straight while others zigzag. The answers, they believe, are related to the energy source and the environment of the jet.

A jet is born at the core of an active galaxy where gas swirls rapidly about a supermassive object, assumed to be a black hole. This whirlpool of gas, called an accretion disk, is probably no larger than our solar system, yet there is more mass in it and the black hole than in 100 million suns. As gas from the outer regions of the galactic nucleus presses in, the gas nearest the black hole compresses and superheats. The temperatures are so great that the atoms in the gas are ionized, stripped of their electrons. This state of matter is called plasma. The plasma that doesn't fall into the black hole spurts out violently along the axis of the black hole's magnetic field at velocities as high as 20 percent the speed of light (37,000 miles per second). This plasma jet is narrow and straight at first but broadens slightly as it bores its way through and out of the galaxy.

Once the jet enters the intergalactic medium, astrophysicists speculate that it encounters a denser medium of hot ionized gas that, over the course of tens of thousands of years, gradually slows the jet's flow. Finally, like a river spilling into a delta, the jet pools into an immense radio-emitting "lobe" well outside the visible disk of the galaxy, an effluvium of millions of years worth of accumulated gas.

Given their enormous energies and velocities, why aren't *all* jets straight? What forces can perturb and reshape a relativistic flow of ionized gas shot from the heart of an active galaxy or quasar?

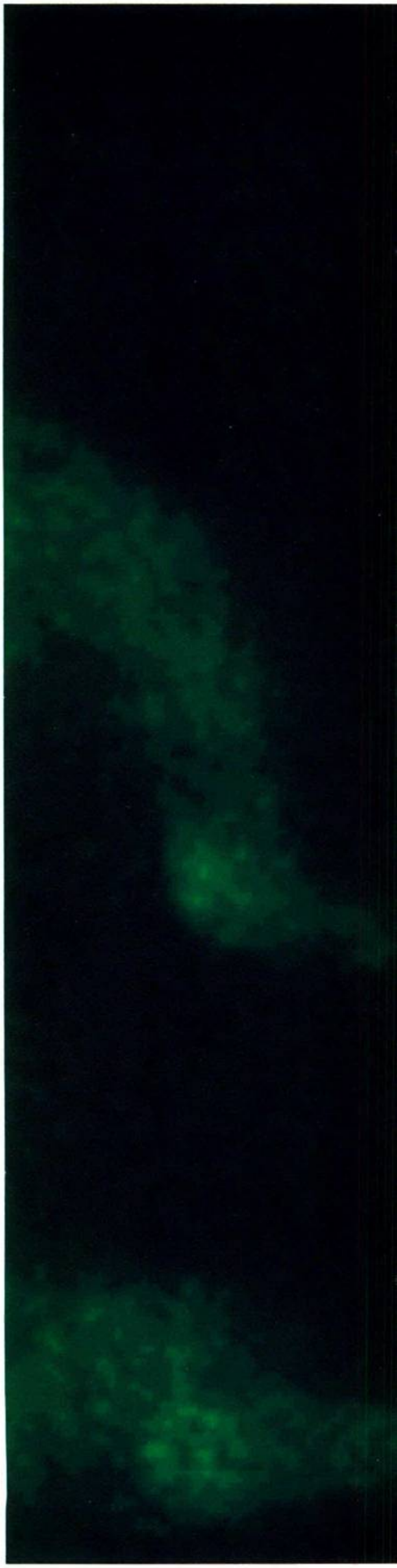
### The Water-Hose Instability

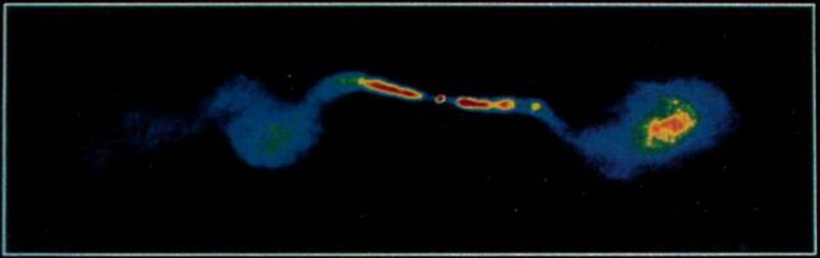
Anyone who has ever played with a flexible garden hose knows a little bit about the physics that shape extragalactic jets. Grasp the hose about four feet from the nozzle so it droops toward the ground, open the valve all the way, and watch the water hose writhe back and forth like a demented snake. Water flowing along the outer bend of the hose must travel a little faster to keep up with the water flowing along the inside bend, which results in a pressure difference. This pressure difference sets up an instability that forces the hose to continually wiggle about.

Jets in active galaxies and quasars exhibit similar instabilities, according to Jack O. Burns, director of the Institute for Astrophysics at the University of New Mexico. "Rather than water flowing through a hose," said Burns, "you have one plasma flowing through another plasma. The first plasma, of course, is the jet, and the second is the hot gas that surrounds the jet, either inside the galaxy or in the intergalactic medium. So the two media rubbing against each other makes the jet unstable."

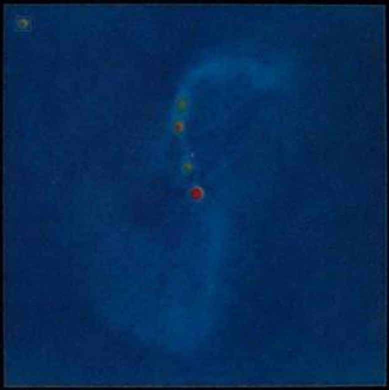
### Tides, Precession, Winds

But not all the bends and twists in jets are attributable to instabilities alone. The jets of many double radio sources — galaxies exhibiting two jets and, thus, two radio lobes — are curved symmetrically so the bend of one jet is a mirror image of the bend of the other jet. Astronomers believe

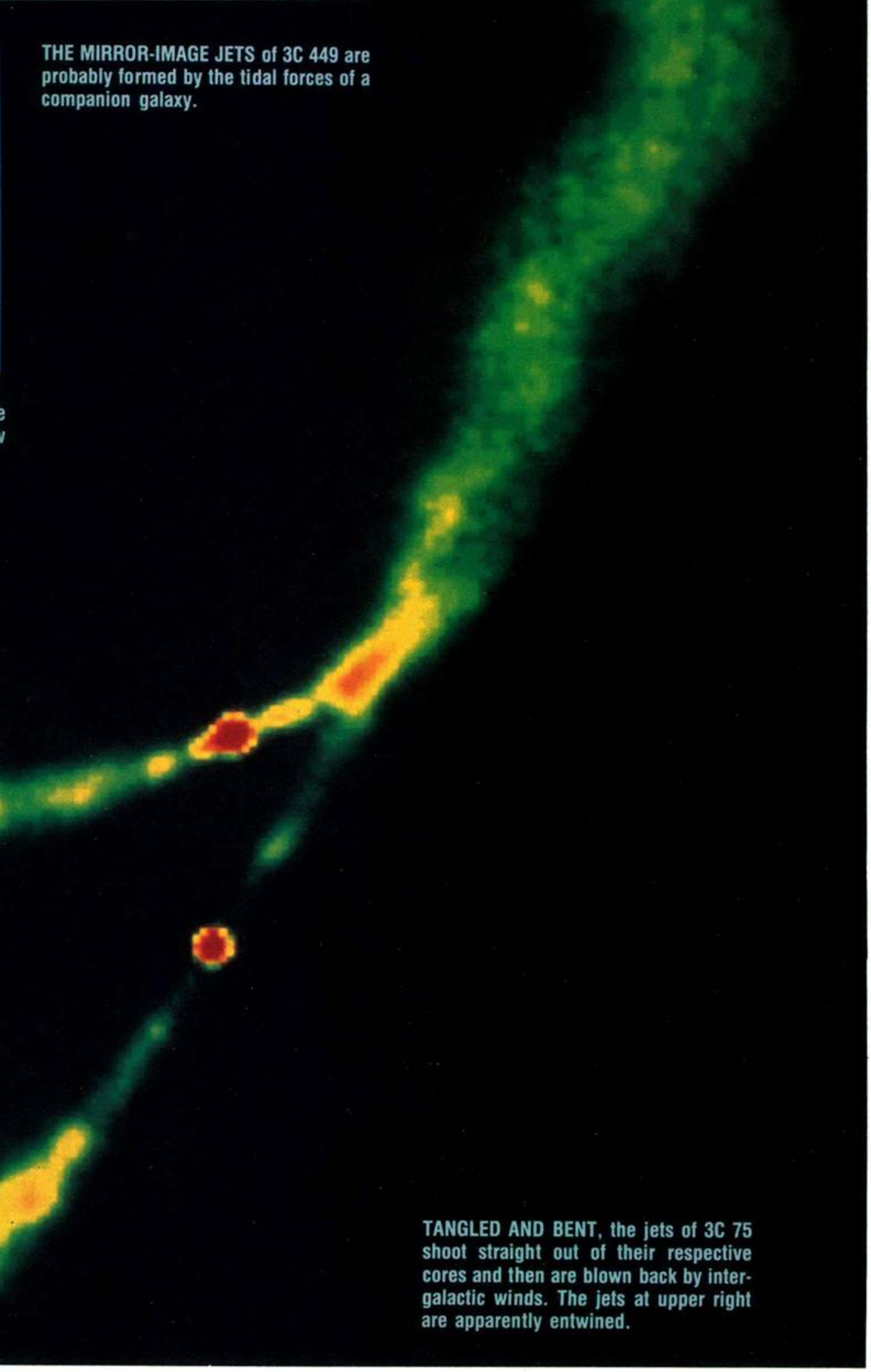




THE MIRROR-IMAGE JETS of 3C 449 are probably formed by the tidal forces of a companion galaxy.

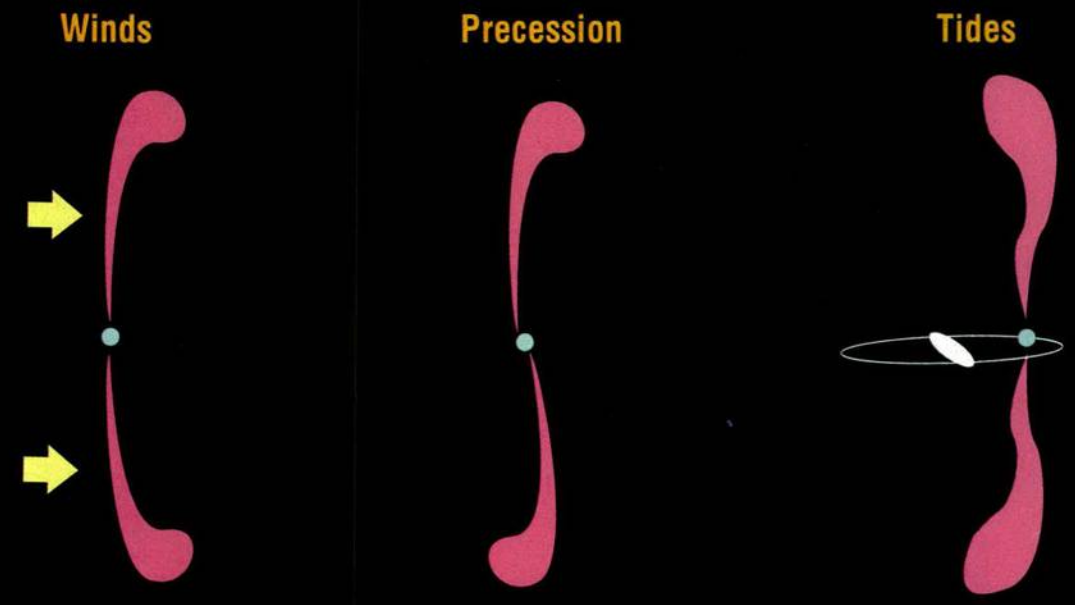


THE S-SHAPED JET emerging from the quasar 2300 −189 is an example of how a spinning core can deform a jet.



TANGLED AND BENT, the jets of 3C 75 shoot straight out of their respective cores and then are blown back by intergalactic winds. The jets at upper right are apparently entwined.

## Forces That Shape Jets



**Winds**

Like windblown smoke, the jets of a "radio trail" source are bent back like a wishbone as the galaxy moves rapidly through the hot, dense gas in galaxy clusters.

**Precession**

Each parcel of gas emerging from a spinning core follows a ballistic trajectory, but collectively the jet describes a loopy appearance in space.

**Tides**

The gravitational pull of another galaxy on the jets of an orbiting companion leads to mirror-symmetrical jets, with one jet reflecting the shape of the other.

these mirror-image jets arise from the tidal effects caused by a companion galaxy.

Another type of jet is probably caused by the precession of the source. "The engine may be precessing, wobbling like a spinning top," said Burns. "That would tend to produce a loopy-looking jet." In the precessional model, parcels of gas are shot out of a continuously spinning black hole. Each parcel follows its own ballistic trajectory, but the location of all the ejected parcels of gas at any one time describes a spiral pattern. One jet tends to curve upward, while the other tends to curve downward, like an "S."

In sources called radio trails, two jets bend back from the nucleus and are either nearly parallel or merge in a vast pool of radio emission.

"The motion of the radio galaxy through the intergalactic medium can distort and shape the jets," said Burns. "That's a kind of wind. We've speculated that a wind inside a galaxy can also disrupt the jet as the result of a shock that exists where the wind from the active galaxy actually contacts the *intergalactic* medium. As the jet propagates through that shock, it can be completely disrupted and turn into one of these diffuse tails that look much like smoke rising from a chimney."

### The Power of the Source

Of course, not all jets can be explained by just one or two of these mechanisms. An integral factor in the ultimate shapes of jets is the power of the engine. In the case of high-power, high-luminosity jets, such as Cygnus A, the velocity of the jet is much greater than about five times the speed of sound in a gas. As a result of their high thrust, these jets interact very little with their environment. "They don't care what's out there," said Burns. "They just plow right through the shocks and often remain very straight."

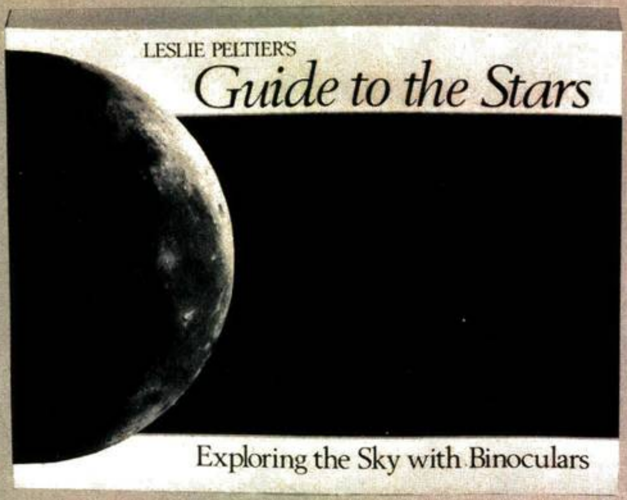
On the other hand, low-power, low-luminosity jets, such as those found in radio trail sources, have lower velocities, though they are still supersonic. "We've clearly demonstrated in our computer models," said Burns, "that such jets are strongly dominated by their environment and not so much by the engine."

In an intermediate category is 3C 75. This radio source has one of the most exotic displays of jets known. Lying at the center of the galaxy cluster Abell 400, 3C 75 corresponds to a single massive galaxy with twin active nuclei each sporting dual jets; two of the jets appear entwined. These jets are fairly luminous and have velocities about five times the speed of sound. Nonetheless, said Burns, "environment does play a role in bending these radio jets. If the nuclei are going around each other, then their motion through the surrounding extragalactic medium should be enough to distort the jets into the two U-shaped tails."

After more than ten years of study astrophysicists admit they still have a lot to learn about the structure and behavior of extragalactic jets. But if they still have problems, they soon will have the tools to solve them. Observationally the next significant step will be taken when the *Hubble Space Telescope* tries to resolve stars near the cores of nearby active galaxies to better understand the central engine, which generates the jets.

In addition, the Very Large Array radio telescope near Socorro, New Mexico, which has so far provided the highest resolution radio images of jets, is planning to add more attennas to its assembly of twenty-seven dishes. This will greatly increase the VLA's resolution capability beyond the current tenth-of-an-arcsecond limit. Greater resolution will allow astronomers to get an even clearer look at the structure of jets.

On the theoretical side, supercomputers and even aerodynamic studies provide astrophysicists with a hands-on approach to modeling jet development and flow while also allowing them to test theories and devise new ones. It's entirely possible that the distant, tangled tails of extragalactic jets will one day be disentangled right here on Earth in a wind tunnel or on a computer screen. □



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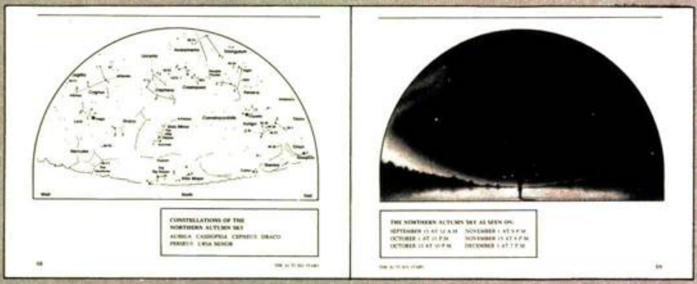

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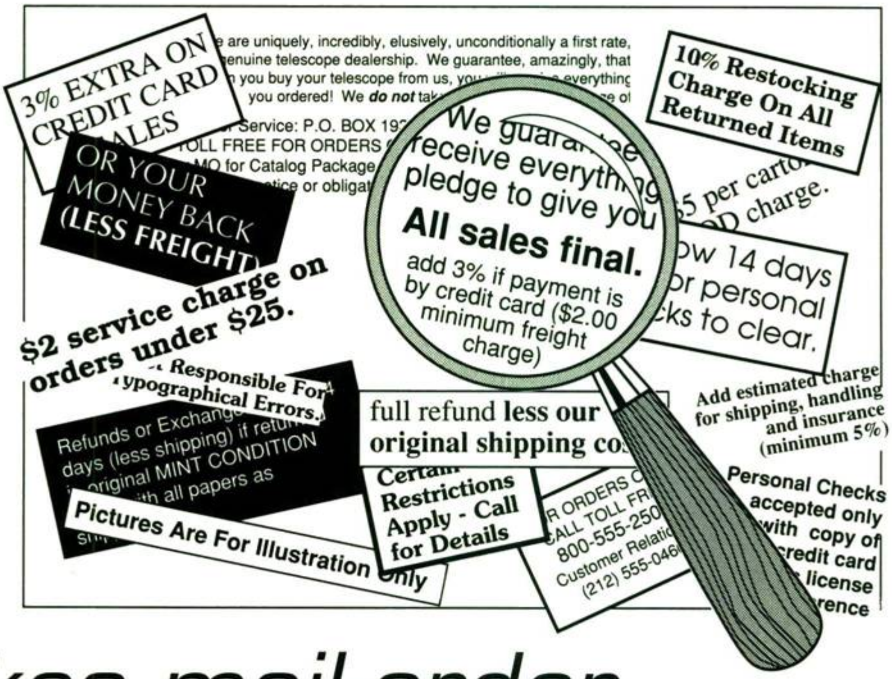
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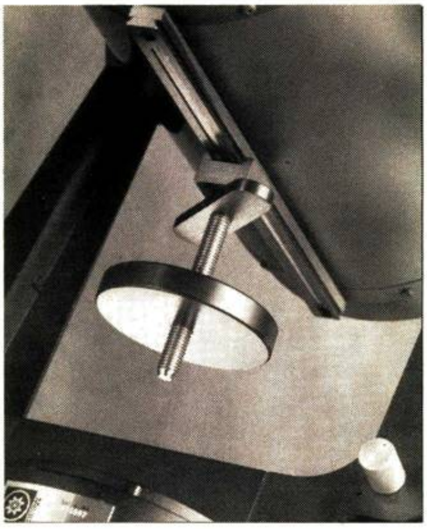

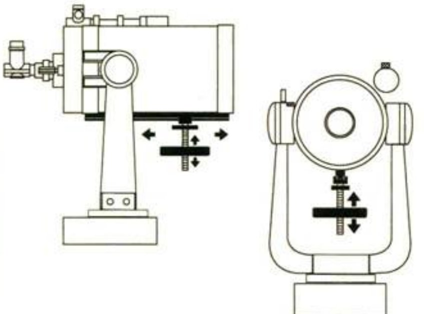

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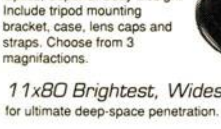

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# The Many Faces of the Sun

### For the first time solar astronomers coordinated simultaneous observations of solar activity across many wavelengths.

by Gerrit L. Verschuur

Astronomers got an unprecedented thorough look at the Sun last September when observatories in eighteen countries took part in a unique observing project called the International Solar Month. By carefully coordinating the observations of astronomers on the ground with those of sometimes temperamental spacecraft, simultaneous pictures of the Sun's disk in a variety of wavelengths, from the x-ray region of the spectrum to the radio, were taken. The preliminary results of the project promise to give solar astronomers a new look at how solar activity grows and develops.

Incredible as it sounds, the International Solar Month was the first time such a simultaneous solar imaging project had ever been carried out at so many wavelengths. In the past, solar astronomers working in different parts of the spectrum have observed the Sun at different times, partly because they were observing different phenomena and partly because scheduling simultaneous observations at a variety of observatories was difficult. An additional factor is that up until recently there hasn't been a large assortment of instruments capable of viewing the Sun across the entire spectrum available at any one time. But because nothing the Sun does occurs solely in one wavelength band, this blinkered approach, however involuntary, has put significant obstacles in the way of any astronomers seeking to understand the processes that govern the Sun's activity.

"We've been like the blind men describing the elephant," says Joe Gurman, project scientist for NASA's *Solar Maximum Mission* satellite observatory. "One guy concludes it's a snake, another thinks it's a tree, and so on."

Another problem facing solar observers working in any wavelength is the sheer unpredictability of the Sun. In contrast, astronomers who study galaxies and nebulae do not as a rule have to respond quickly to transient events. (Supernova 1987A in the Large Magellanic Cloud was a rare exception.) An image taken of a galaxy at one wavelength can be compared with one taken on a different night in another wavelength. But solar astronomers know they can't simply assume one x-ray image of the Sun is as good as another. Even apart from the fact that the Sun is always presenting a new face to view as it rotates on its axis, solar activity is far too variable. In fact, its changeability is important by itself, because vital clues to understanding the Sun lie precisely in these variable events — and even those solar astronomers who are not studying the Sun's active regions need to know how these events fit into the overall picture.

Considerations such as these led Joan Schmelz, a scientist with *Solar Max*, to organize the multinational research effort. "Most solar physicists agree," she said, "that what we need in order to understand more about solar flares and active regions on the Sun are simultaneous multiband observations."

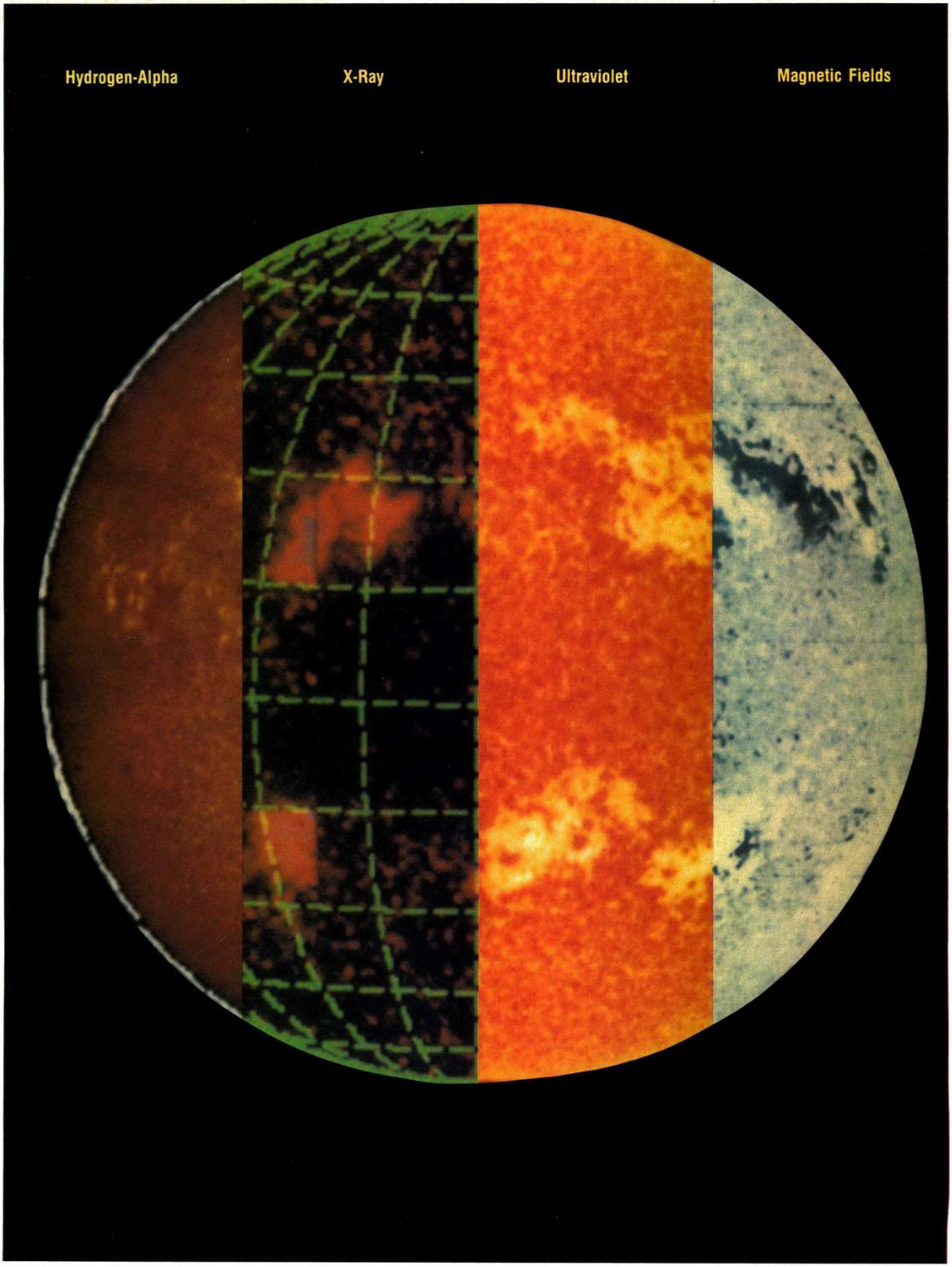
"Given the sensitivity of present day instruments," added Gurman, "we can most profitably study the Sun's active regions and then take a look at the whole corona." The corona is the Sun's tenuous outer atmosphere, visible from the ground during a total solar eclipse when the Moon blocks the light of the photosphere, the Sun's visible surface. Its pearly white beauty and delicate structure conceal a major solar mystery. For decades astronomers have struggled to understand why the corona should have a temperature of about 2 million kelvins, while the photosphere only a short distance beneath it is a mere 6,000 kelvins. Several explanations have been suggested, but none is totally satisfactory.

"One of the greatest problems confronting solar physics," Gurman said, "is that we still do not know why the corona is so hot."

The International Solar Month was proposed in the hope it would attack specific problems, such as relating what happens in the photosphere to the events that occur in the corona, and provide the critical synthesis to help "define the elephant."

Yet the International Solar Month would never have come to pass if a Soviet scientific delegation had not visited the United States in April 1988. During the Soviet visit, experts from the various *Solar Max* instrument teams met informally with two of the Soviet scientists. The scientists realized that an East-West collaboration could create the first stereoscopic solar images. The plan was to take simultaneous pictures of the Sun from the Soviet *Phobos 1* craft on its way to Mars and from the American *Solar Max* satellite in Earth orbit. Just as humans view a scene with both eyes and interpret distances and three-dimensional structures from the slightly different view each eye provides, the wide baseline between the two spacecraft would mean that simultaneous photos would reveal the structure of the Sun's

**RED SUN, GREEN SUN, ORANGE, AND WHITE** — our nearest star showed off a few of its many faces to astronomers during the International Solar Month last September.


Hydrogen-Alpha
X-Ray
Ultraviolet
Magnetic Fields

# Comparing 'Different' Suns

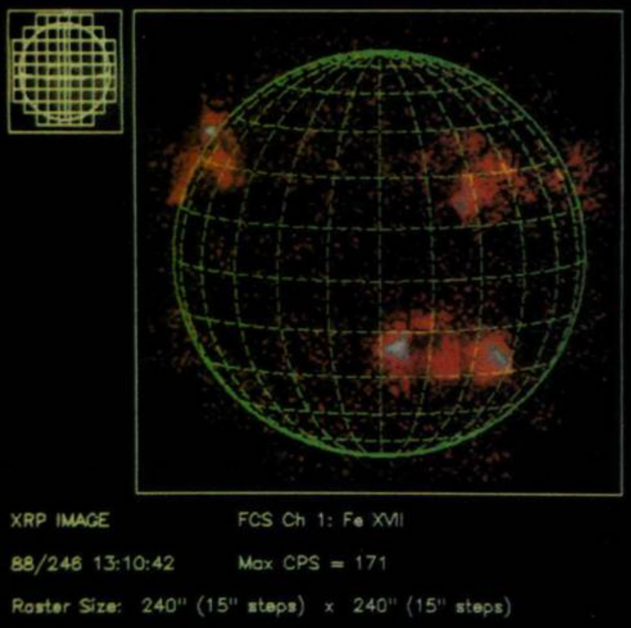
As the Sun now enters the "rapid-rise" part of the 11-year sunspot cycle, active regions are becoming more common and show greater energy in their outbursts. The eruptions of an active Sun embrace a wide temperature range and the phenomena are visible at many wavelengths.

When you compare these pictures — taken on September 2 and 3, 1988 — you can see that bright active regions (white places in the hydrogen-alpha image) show up in other wavebands as well. (North is up and the Sun is rotating from left to right.) Moreover, the structure of the disturbed regions also persists across the spectrum. For instance, notice how the double-centered region in the lower right is visible in all the images that show the disk.

Note also how the magnetogram at upper right on the opposite page shows the characteristic dipolar nature of solar magnetic fields. Patches of negative polarity (black) and positive polarity (white) flank the active regions. In the northern hemisphere the leading fields are negative, while the opposite is true in the southern hemisphere. In the next sunspot cycle 11 years from now, the leading polarities will be positive in the north and negative in the south. Thus, solar magnetic activity in reality has a 22-year cycle.

All the images were made from the ground except the x-ray and ultraviolet ones; these were taken from Earth orbit by the *Solar Maximum Mission* satellite because Earth's atmosphere is opaque at these wavelengths. In the visible-light image of the corona the Sun's bright photosphere is hidden by an occulting disk about 50 percent bigger than the real solar diameter.

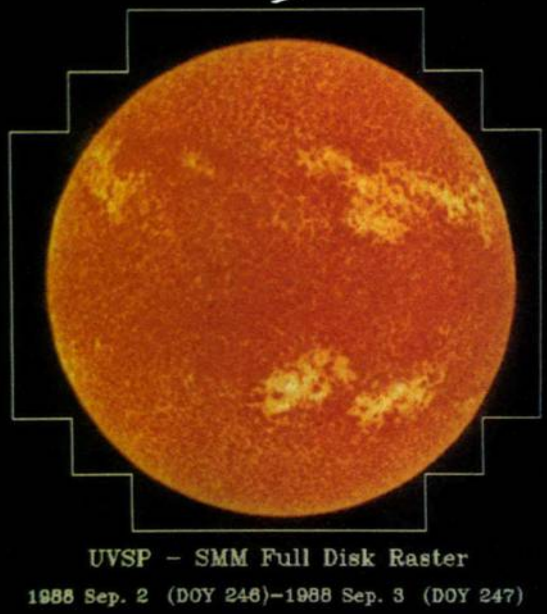
**X-RAY** shows regions 100,000 kilometers above the photosphere at temperatures of 3 million to 4 million kelvins.



**Gamma Ray**

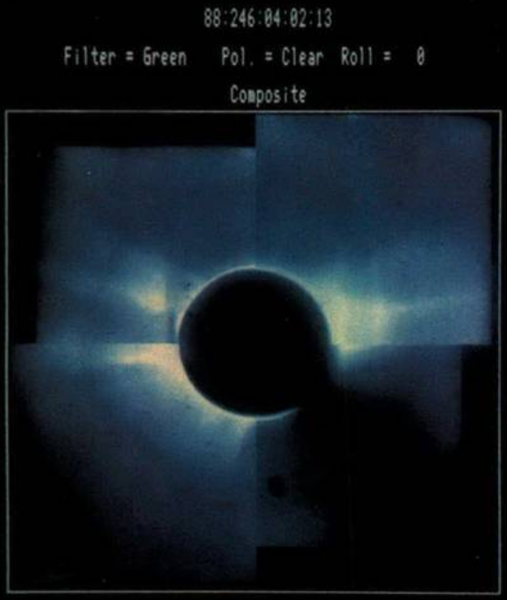
**X-Ray**
**15 angstroms**

**Ultraviolet**
**1370 angstroms**

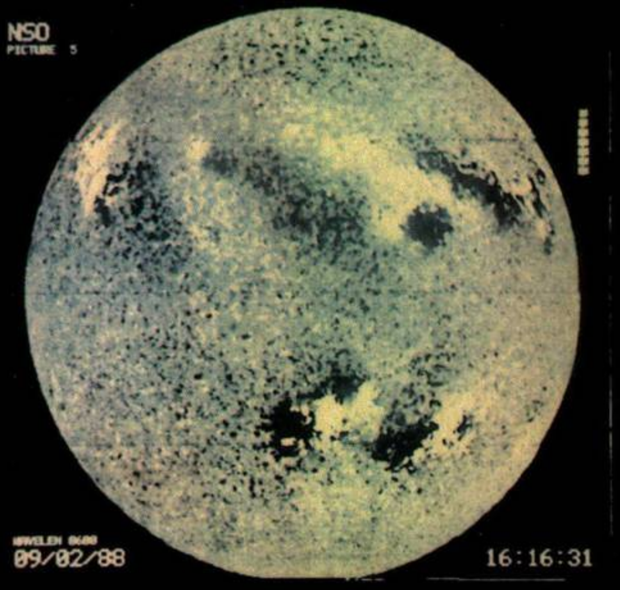

UVSP - SMM Full Disk Raster
1988 Sep. 2 (DOY 246)-1988 Sep. 3 (DOY 247)

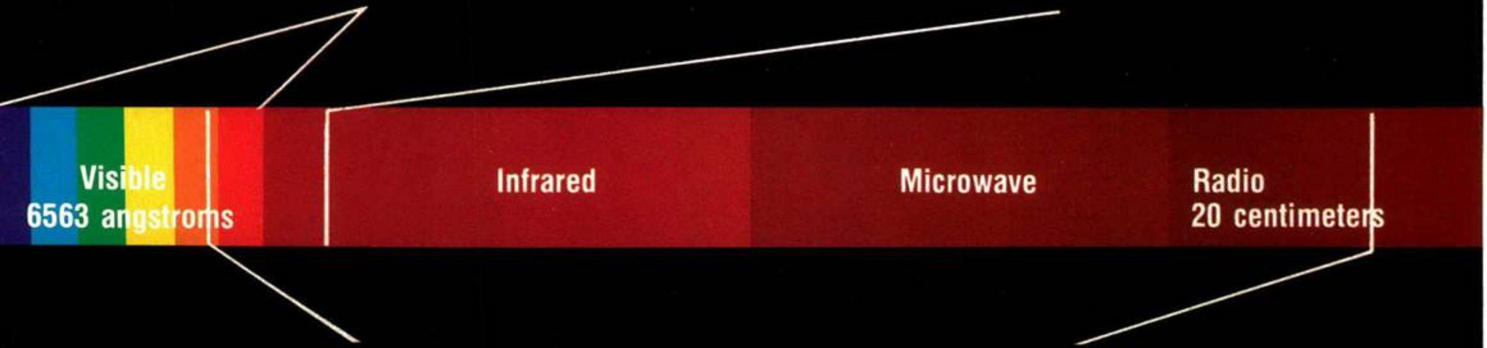
**ULTRAVIOLET** samples just above the photosphere where temperatures run to 50,000 kelvins.

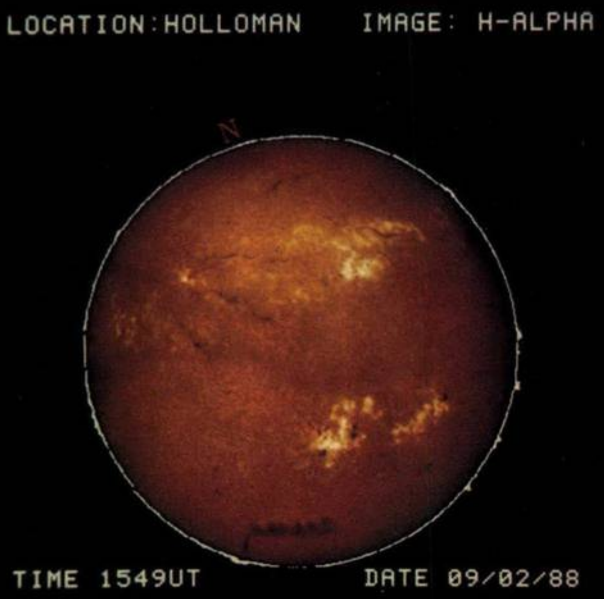
**VISIBLE** light shows the corona extending a million kilometers from the surface (note the different scale).


88:246:04:02:13
Filter = Green Pol. = Clear Roll = 0
Composite

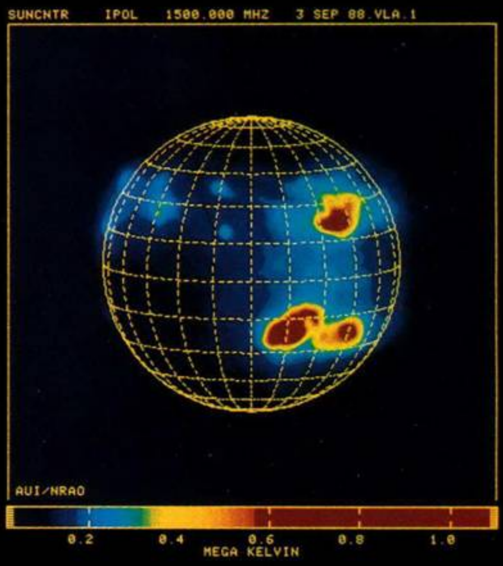
**MAGNETIC FIELDS** in the photosphere can be thousands of times stronger than that of Earth. White shows positive polarity, black negative.


NSO
PICTURE 5
WAVELEN
09/02/88
16:16:31


Visible
6563 angstroms
Infrared
Microwave
Radio
20 centimeters


LOCATION:HOLLOMAN IMAGE: H-ALPHA
N
TIME 1549UT DATE 09/02/88

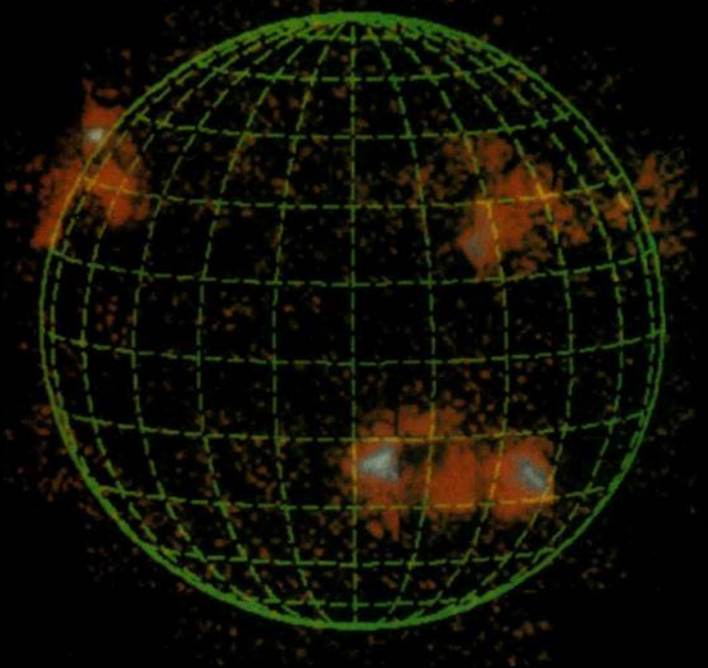
**HYDROGEN-ALPHA** portrays the photosphere where active regions appear bright.



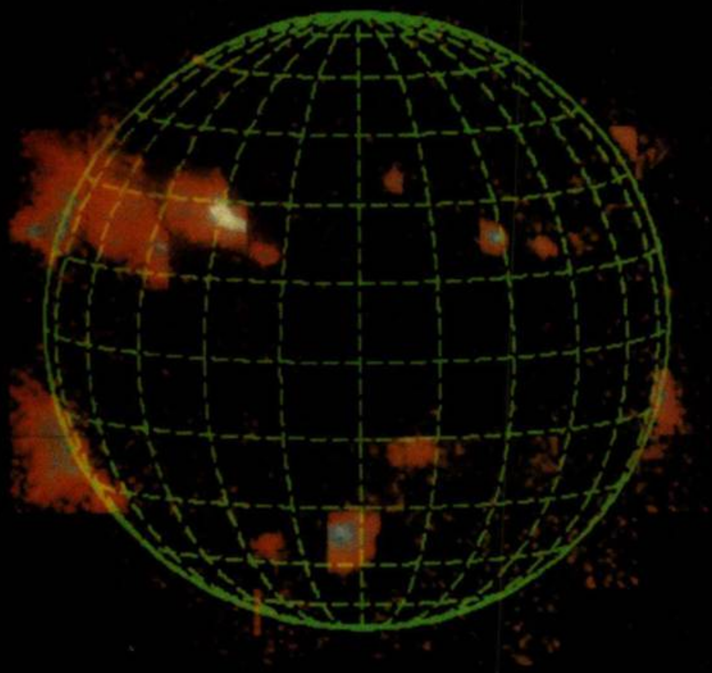
**RADIO** samples gas at the same altitude as x-rays but targets a different kind of emission mechanism.

# As the Sun Turns

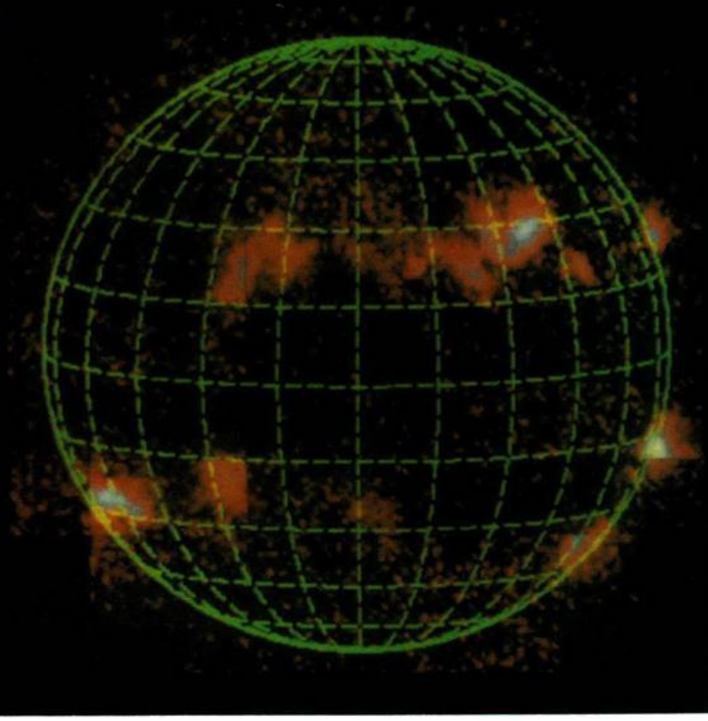
**X-ray images taken on three dates last September track changes in the hot gas of the lower corona as the Sun slowly rotates from left to right. (One full turn of the equator takes 28 days.)**



**SEPTEMBER 2:** Bright, active regions show where the gas has been heated to millions of kelvins by mechanisms still not fully understood.



**SEPTEMBER 22:** Solar rotation is bringing new hot spots into view. The active region in the southwest on September 2 now glows on the eastern (left) horizon.



**SEPTEMBER 27:** Almost one rotation after the first photo, some of the original features are back in view. The mid-northern disturbance is now crossing the meridian.

corona in three-dimensional detail.

Because the solar corona is so hot, the astronomers felt that photos taken at x-ray wavelengths offered the best look at what was going on in the corona. *Phobos 1* carries a Czechoslovakian-built instrument called TEREK, designed to image the Sun at x-ray wavelengths. The collaborative plan called for TEREK to photograph the solar corona during the craft's long coast out to Mars, while *Solar Max* would do the same from Earth orbit. Joan Schmelz then mentioned to the Soviets that several groups of solar astronomers had requested time on the Very Large Array (VLA) radio telescope in September when the movable antennas of the array would be placed in a good configuration for imaging the solar disk. She also said this was when the instruments on board *Solar Max* were scheduled to make simultaneous high-quality observations in conjunction with the VLA.

The opportunity was too good to pass up. The Soviet and American scientists agreed to collaborate and thus the idea for the International Solar Month was born. The next step was to invite the participation of other solar astronomers from around the world. This had the happy effect of broadening the pool of ideas and widening the wavelength range covered. The plan of action the astronomers eventually decided upon for the September 1988 collaboration called for solar forecasters at NASA's Goddard Space Flight Center in Greenbelt, Maryland, to predict on a day-to-day basis which active region was likely to burst into violent eruption. These alerting messages and essential information for observers were to be sent by electronic mail and telex to the participating astronomers who would then focus on "the target of the day."

"Without electronic mail," says Schmelz, "this program would have been quite impossible. Daily communication was essential."

*Phobos 1* was successfully launched last July and calibration tests of TEREK produced good x-ray images of the Sun. Everything appeared set for the International Solar Month when disaster struck. Because of an error by a flight controller, contact with *Phobos 1* was lost in the last days of August, and despite heroic efforts by the Soviet ground controllers it was never re-established. Ironically stereo images of the Sun could still have been taken before the Soviets lost contact with their probe if the *Solar Max* scientists had coordinated with TEREK's calibration tests. But because the agreed-on period of joint observations had not yet begun, TEREK took calibration images unduplicated by *Solar Max*. (Although the unaffected *Phobos 2* craft doesn't carry a TEREK instrument, it can contribute more limited solar data from other instruments onboard.)

Right on the heels of the *Phobos 1* accident came another that affected *Solar Max* itself. On August 31 the wavelength drive of the crucial Flat Crystal Spectrometer, part of the x-ray imager on *Solar Max*, stuck in place. The only good news was that it jammed at 15 angstroms, the wavelength of the most sensitive "soft" x-ray line used to study active regions.

The stuck instrument wasn't completely broken, but its use involved a tradeoff. For example, in its fully operational (unstuck) state, the spectrometer could either fix its gaze on one small part of the Sun, recording the x-ray spectrum emitted by that part, or it could image large sections of the solar disk at some fixed wavelength. In terms of the scientific return the tradeoff boiled down to this: imaging provides information about structures on the Sun, while spectra are important for determining temperatures and densities. Flight controllers made several ingenious attempts to loosen the drive, but all proved unsuccessful. Compelled finally to pick one mode or the other, the *Solar Max* astronomers chose to use the spectrometer as an imager alone. This transformed the second mishap into an opportunity, because it meant *Solar Max* could contribute pictures to fill an important gap in the wavelength coverage for the International Solar Month project.

On September 2, instruments on *Solar Max* were commanded to produce images of the Sun at x-ray and ultraviolet wavelengths. At the same time *Solar Max*'s coronagraph, an instrument containing an artificial Moon that blocks the light of the photosphere, imaged the corona in white light (all visible colors). Simultaneously ground-based telescopes produced an image of the Sun in hydrogen-alpha (a spectral line produced by excited hydrogen) and constructed a magnetic field map. One day later, when the Sun had as yet rotated very little, astronomers at the VLA and the 1,000-foot dish at Arecibo, Puerto Rico, made a map of the radio Sun. The Sun had never before been viewed in so many "colors" all at once.

**Until astronomers could observe the Sun at many wavelengths simultaneously, they were like the proverbial blind men trying to describe an elephant.**

Because the spectrometer's wavelength drive had jammed, astronomers found themselves with extra time to make more images of the full disk at x-ray and ultraviolet wavelengths. Building up these images required eight or nine Earth-orbits of the spacecraft because the pictures are a mosaic of many small fields of view. On September 22 and 27, *Solar Max* was at it again, and ground-based telescopes joined in once more.

To cap the final day of the campaign — and much to the delight of everyone involved — a large flare burst out in the target region. Participating observatories monitored its evolution carefully. This event and the data record of it will allow astronomers to study how a flare develops. They are especially interested in devising models to explain how the energy-release mechanisms work and the temperatures in various parts of the flare change.

Now that it's been done once, other International Solar Months will likely be penciled into solar astronomers' observing calendars. Difficulties still remain in coordinating telescope time across national — and institutional — boundaries. But the outstanding success of this pioneering venture in worldwide solar astronomy points the way for a much more sophisticated understanding of our nearest star. ☐

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*Gerrit L. Verschuur is a freelance science writer and researcher who lives in Bowie, Maryland. He is the author of* Interstellar Matters, *published by Springer-Verlag. Verschuur's most recent article, "Barnard's 'Dark' Dilemma," appeared in the February 1989 issue.*

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# LUMICON FOR HIGH PERFORMANCE

## ASTROPHOTO OF THE MONTH

**The "Flame Nebula" NGC 2024 in Orion.** Also known as the "Christmas Tree" or the "Tank Trucks" nebula. NGC 2024 is seen best usually with either a LUMICON DEEP-SKY or UHC filter. Photo by Don N. Reiners, 16" f/5, 40 min. using hypered 2415 film and a LUMICON 2" EASY-GUIDER.

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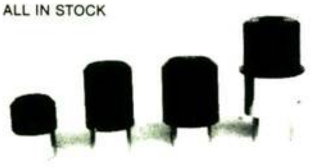

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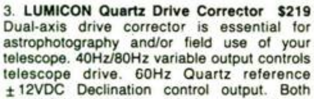

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**LUMICON SKY VECTOR™ computer, showing digital readout of coordinates, and easy-to-use controls. Shaft encoders are included** (not shown). The coordinates are for Minkowski 1-79, a 13th mag. planetary nebula.

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- Digital right ascension readout to 1 minute of R.A.
- Digital decl. readout to 10 arc-min
- Digital altitude readout to 1°
- Motor drive ***not required!***
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- Just sight two stars!

The computer's sophisticated program (over 3000 lines of code) determines **everything** from an initial sighting of just two stars!

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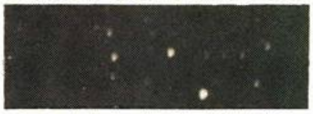
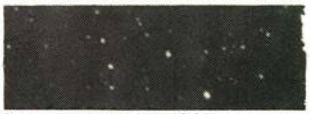
| *Sky Catalogue 2000.0*, Vol. II, doubles, variables, deep-sky objects | **$29.95** |

## COMA CORRECTOR



**Coma 1 inch off-axis 17½" f/4.5**



**Same field with LUMICON coma corrector; smaller, more numerous stars.**

This computer-designed LUMICON 2" lens reduces coma and flattens the field for both viewing and photography. It threads into LUMICON 2" EASY-GUIDERS for effortless installation. This lens is optimized for f/4.5 and reduces aberrations for f/3.5 to f/5 Newtonians. Off-axis images are much smaller, making off-axis guiding far easier and yielding round pinpoint star images in photos. Since star images are sharp over a full 2¼" circle, you can use medium format cameras in addition to 35mm cameras. This zero power lens does not change image scale nor shift focus, and all lens surfaces are multi-coated for highest efficiency. Although designed for photography you may also use this lens to improve image quality in wide-field viewing with low power eyepieces.

| | |
|---|---|
| LUMICON Coma Corrector/Field Flattener Lens | **$285.00** |
| LUMICON 2" EASY-GUIDER | **$169.50** |
| 2" EASY-GUIDER (Mamiya 645) | **$199.50** |
| Adapter for Hasselblad | **$185.00** |
| Adapter for Bronica SQ-A | **$175.00** |
| 2" Extension for viewing | **$26.00** |

## 1.5x, 1.8x MULTIPLIER LENS

**1.8x Multiplier Lens**

The computer-designed LUMICON 2" Multiplier/Field Flattener multiplies the image scale in photography by 1.8x (f/4.5 becomes f/8). Use it with any LUMICON 2" EASY-GUIDER. It multiplies by 1.5x without the included extension tube. This lens is optimized for f/4.5, but will work well with any optical system. It may also be used visually as a highly corrected 2" Barlow lens.

| | |
|---|---|
| LUMICON 1.5x/1.8x multiplier lens | **$195.00** |

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LUMICON now offers 3 different low-profile helical focusers. They stand only 1¼-1½" above the telescope tube. Use the 1¼" or 2" versions for viewing. Use the 2" non-rotating focuser for convenient photography with the LUMICON 2" EASY-GUIDER™.

**Select your desired base-plate shape!** Flat, 7" OD, 9½" OD, 12½" OD, 16" OD, 21" OD, SUPER-FINDER base plate.

| | |
|---|---|
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| **LUMICON Non-rotating Helical Focuser** | **$79.50** |
| 2" rack & pinion low profile focuser | **$139.00** |
| 3 handles (see photo) for non-rotat. focuser | **$12.95** |
| **2"/1¼" adapter** w/48mm filter threads | **$20.00** |
| **2" LUMICON EASY-GUIDER** | **$169.50** |

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| | |
|---|---|
| Digital readout system for 2080/2120/LX6 | **add $475** |
| 8200 object memory CAT computer | **add $1195** |

**NEW 2080/LX6 $1945**

Meade
2358
356

**Meade Model 2080/LX6:** The most advanced Schmidt-Cassegrain telescope available today. The hand-held electronic command center controls all telescope functions, and has digital coordinate readout available as an option. The f/6.3 optics yield 2½x shorter exposures in astrophotography.

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| MTS-SC8 w/LX3 drive, MCOG | **$1198** |
| 2080/LX3, 8" f/10 w/MCOG | **$1389** |
| 2080/LX5, 8" f/10 w/MCOG | **$1589** |
| 2120/LX5, 10" f/10 w/MCOG | **$1995** |
| 2120/LX3, 10" f/10 w/MCOG | **$1799** |
| 2045/LX3 4" f/10 w/LX3 drive | **$795** |
| #39 declination motor for LX5 | **$109** |
| #38 (LX3) or #38A (2045) dec. mtr. | **$99** |
| Dew shield - essential! 8" **$65;** 10" | **$98** |
| LUMICON EASY-GUIDER for 2080 | **$225** |
| EASY-GUIDER (f/4-f/10) for 2120 | **$395** |
| CAT command control, 8200 objects | **$1195** |

## MEADE SCHMIDT-NEWTONIAN TELESCOPES

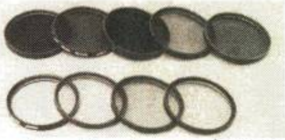
| | |
|---|---|
| MTS-SN6, 6" f/5, #788 drive | **$649** |
| MTS-SN6 w/drive, MCOG | **$698** |
| MTS-SN8, 8" f/4 w/drive, MCOG | **$795** |
| MTS-SN8, 8" f/4 w/LX3 drive, MCOG | **$1048** |
| #36 LX3 hand cntrl. & #38 dec. motor | **$189** |

## MEADE NEWTONIAN TELESCOPES

| | |
|---|---|
| Model 826C 8" f/6 w/motor, 2" focuser | **$975** |
| Model DS-10A, 10" f/4.5 w/mtr., 2" focus. | **$975** |
| Model DS-16A, 16" f/4.5 w/motor, 2" focuser | **$1975** |
| Model DS-16A w/Sealmaster ball bearings for photography | **$2195** |
| 8X50mm finderscope w/brackets for DS-10,-16 | **$109** |

# LUMICON ACCESSORIES

## 48mm COLORED GLASS FILTERS



These 48mm Filters thread into LUMICON EASY-GUIDERS and most 2" eyepieces. Use adapter for 1¼" eyepieces. AR Coated.

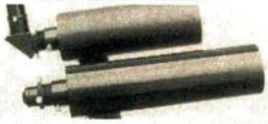
| **Filter:** | **Bandpass** | **Trans** | **Price** |
|---|---|---|---|
| **Ultraviolet** | 320-420nm | 85% | **$35** |
| **Minus Violet** | 420nm-IR | 96% | **$29** |
| **Blue Tricolor** | 340-470nm | 80% | **$35** |
| **Hi Perf. Blue** | 300-540nm | 95% | **$35** |
| **Yellow** | 480nm-IR | 98% | **$18** |
| **Green** | 490-590nm | 60% | **$18** |
| **Orange** | 560nm-IR | 98% | **$18** |
| **Red** | 600nm-IR | 98% | **$18** |
| **H-Alpha Pass** | 640nm-IR | 95% | **$35** |
| **Cyan** | 340-580nm | 95% | **$59** |
| Adapter for 1¼" eyepieces | | | **$20** |
| Set of all 10 48mm filters ($340 list) | | | **$298** |

## EYEPIECE PROJECTION

These adapters allow high magnification photography of the Moon and Planets using eyepiece projection. They may be used without any eyepiece for prime-focus photography. All adapters use standard camera T-rings.

| | |
|---|---|
| Tele-Extender for Meade or Celestron SCT. | **$32** |
| 1¼" Basic Camera adapter, 2 part system | **$32** |
| 0.96" Basic Camera adapter, 2 part system | **$32** |
| 1¼" prime Focus adapter, fits 1¼" focuser | **$22** |
| 0.96" prime Focus adapter, fits 0.96" focuser | **$22** |
| Camera T-ring, specify 35mm camera type | **$12** |

## LUMICON 50mm, 80mm SUPER-FINDER™



Visual Astronomers prefer the LUMICON 80mm SUPER-FINDER™, since hundreds of deep-sky objects, including most Messier objects, are visible directly. SUPER-FINDERS also make nice small portable telescopes. 80mm aperture, F=300mm coated achromat. The deluxe SUPER-FINDER uses an 80mm, F=500mm air spaced achromat.

| | |
|---|---|
| 1¼" 50mm Finderscope **$59.50**, right-angle | **$89.50** |
| 1¼" straight-thru 80mm SUPER-FINDER | **$169** |
| 1¼" right-angle version, w/star diagonal | **$195** |
| 2" right-angle version, non-rotating focuser | **$199** |
| 1¼" Deluxe right-angle Super-Finder* | **$279** |
| 2" Deluxe right-angle Super-Finder* | **$309** |
| 25mm Cross-hair 1¼" eyepiece (12X) | **$29** |
| *1¼" Star Diag. **$32**, 2" Star Diag., silver, | **$145** |
| 1¼" Amici Prism diag. for correct left-right views | **$69.50** |

## 2'' ADAPTERS MEADE, CELESTRON TELESCOPES

These adapters convert refractors and Schmidt-Cassegrain telescopes for 2" operation. They allow use of 2" accessories, such as the LUMICON 2" EASY-GUIDER for photography. They also allow use of 2" eyepieces and/or 2" star diagonal for viewing.

| | |
|---|---|
| 2" adapter for C-8, Meade 2080, etc. | **$26.00** |
| 2" adapter for Criterion 4000, 8000 | **$26.00** |
| 2" adapter for C-80, C-90, C-100 | **$39.50** |
| 2" adapter for C-70, C-80F, C-90F, C-100F | **$39.50** |
| 2" Accessory adapter for Comet Catcher*, C-6*, Meade 310, 320 refractor | **$30.00** |
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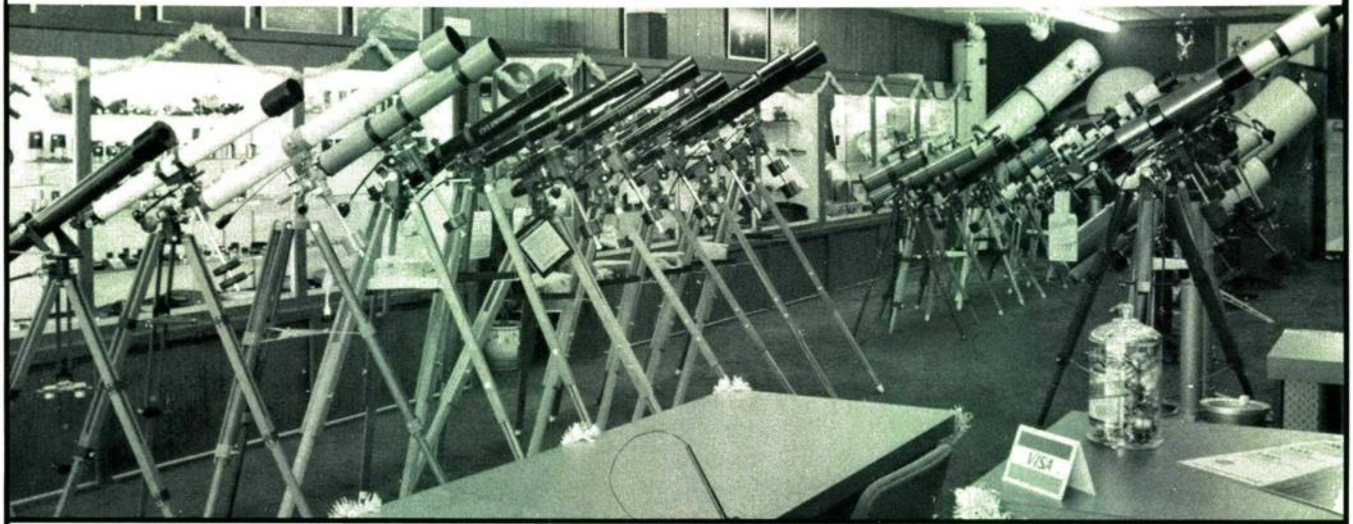

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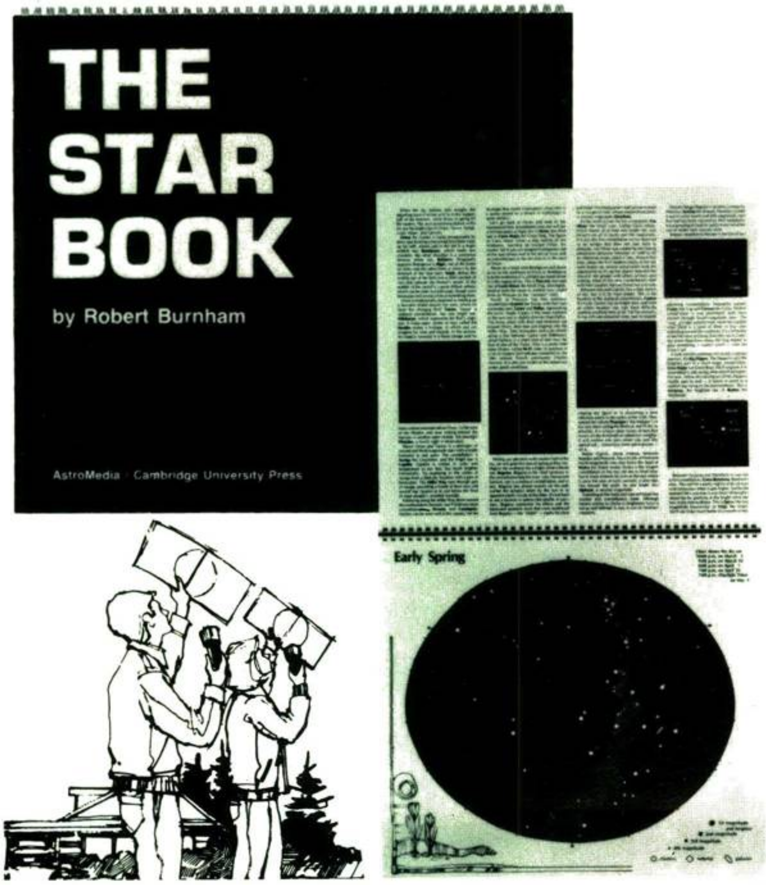

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AstroMedia · Cambridge University Press

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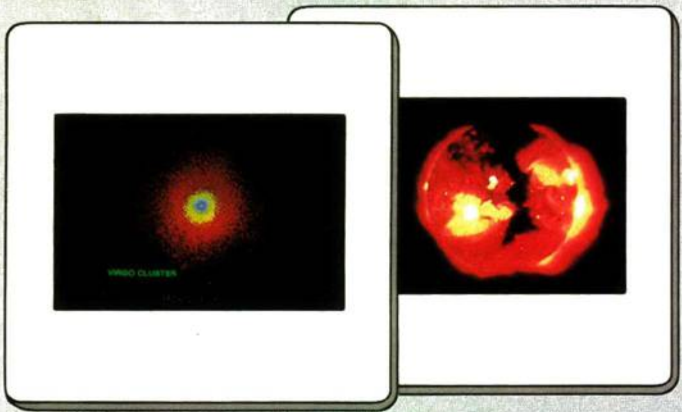

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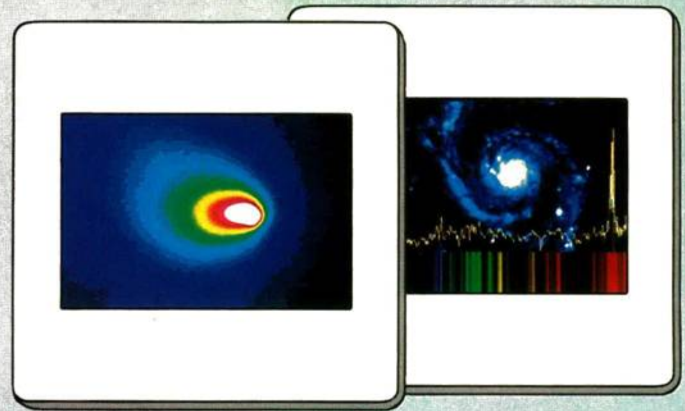

**These computer-processed images illustrate a sample of the new techniques now available to astronomers. Solid-state electronic light sensors and computers combine to produce unique and revealing images of the universe. Taken at the Smithsonian's Observatory in Arizona and reconstructed at the Harvard-Smithsonian Center for Astrophysics. 40 color slides. #30148**

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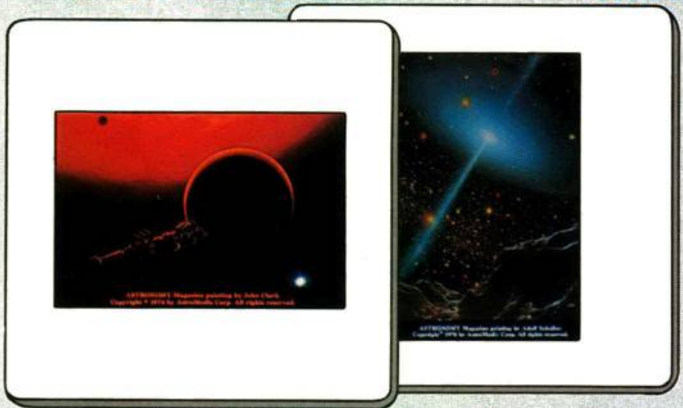
ASTRONOMY Magazine painting by John Clark
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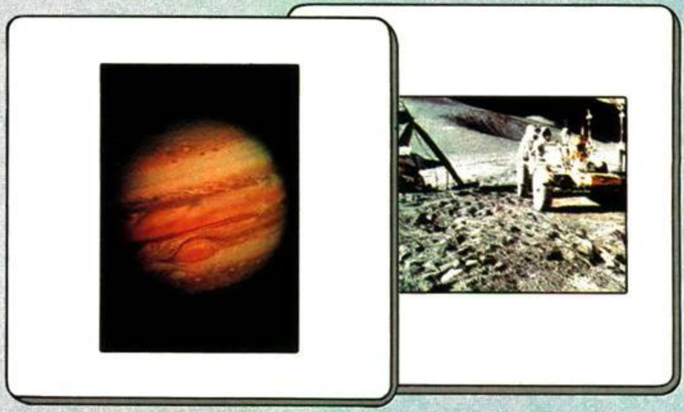

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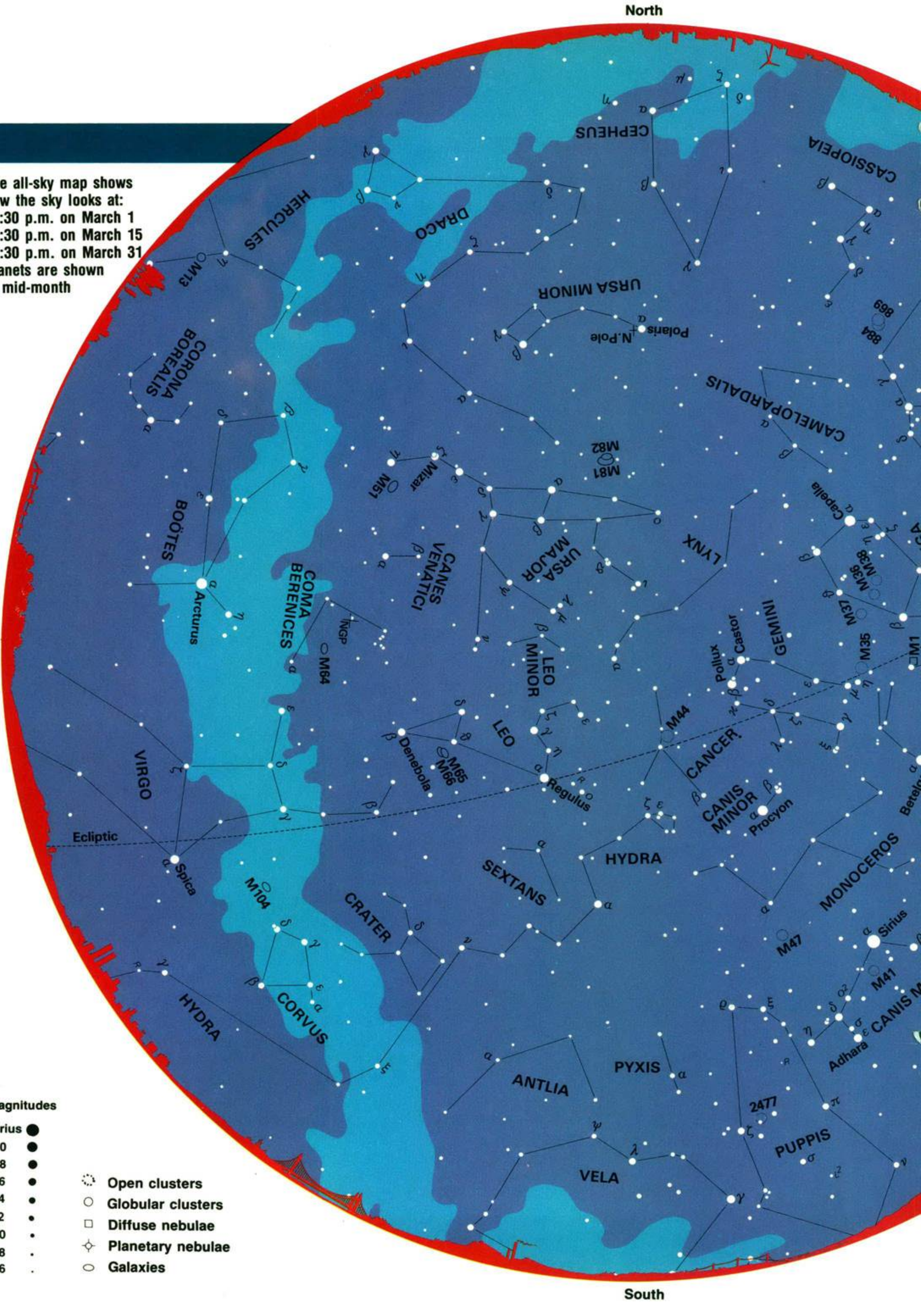
The all-sky map shows
how the sky looks at:
10:30 p.m. on March 1
9:30 p.m. on March 15
8:30 p.m. on March 31
Planets are shown
at mid-month


North
CEPHEUS
CASSIOPEIA
DRACO
HERCULES
M13
URSA MINOR
Polaris
N.Pole
869
884
CORONA BOREALIS
CAMELOPARDALIS
M82
M81
M51
Mizar
Capella
BOÖTES
CANES VENATICI
COMA BERENICES
URSA MAJOR
LYNX
Arcturus
NGP
M64
LEO MINOR
GEMINI
Castor
Pollux
M38
M36
M37
M35
M1
East
LEO
M44
CANCER
Denebola
M65
M66
VIRGO
Regulus
CANIS MINOR
Procyon
Betelgeuse
Ecliptic
Spica
HYDRA
SEXTANS
MONOCEROS
M104
CRATER
M47
Sirius
M41
CANIS MAJOR
Adhara
CORVUS
HYDRA
ANTLIA
PYXIS
2477
PUPPIS
VELA
South

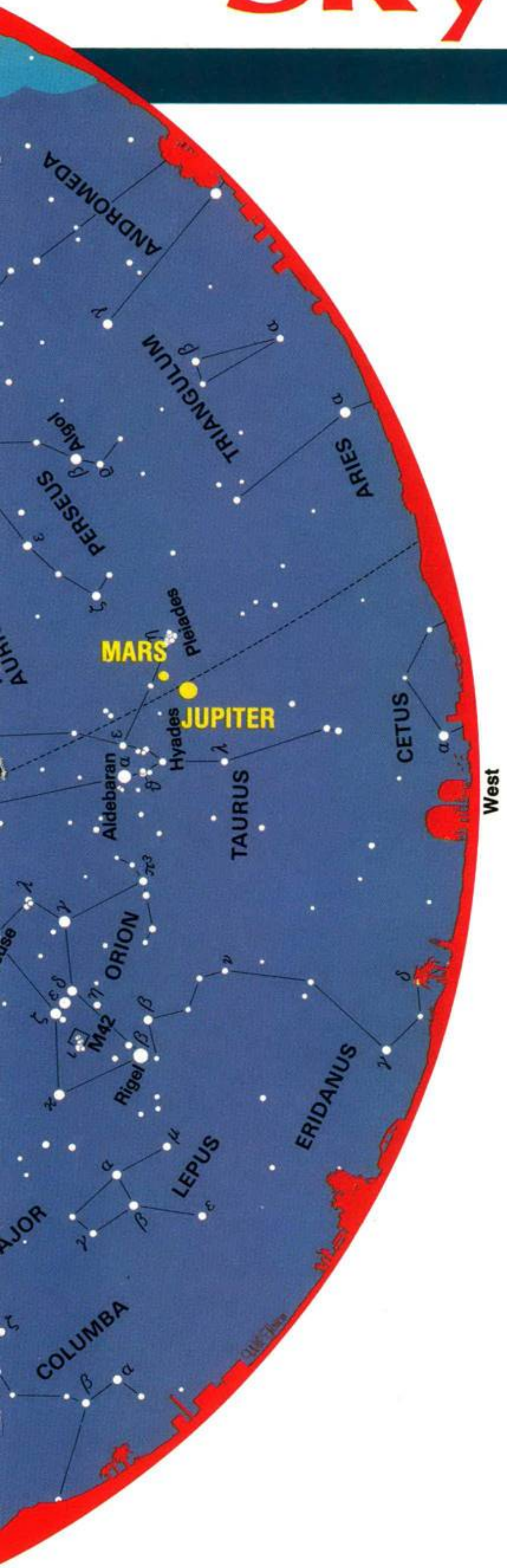
**Magnitudes**

| | |
|---|---|
| Sirius | ● |
| 0.0 | ● |
| 0.8 | ● |
| 1.6 | ● |
| 2.4 | • |
| 3.2 | • |
| 4.0 | • |
| 4.8 | · |
| 5.6 | · |

⁘ Open clusters
○ Globular clusters
□ Diffuse nebulae
✧ Planetary nebulae
⬭ Galaxies

# Sky Almanac

## MARCH 1989



### SOLAR ECLIPSE ON MARCH 7

Observers in the western half of North America can see a partial solar eclipse on the morning of March 7. The Moon covers more than half the Sun in the Pacific northwest and up to 80 percent at maximum eclipse over Alaska.

### MARS SWEEPS PAST JUPITER

The Red Planet makes a close pass by Jupiter in mid-March. The two planets lie less than 2° apart on the evenings of March 10 and 11 and are joined by the crescent Moon on March 12.

### SATURN AND NEPTUNE TOGETHER

Saturn and Neptune pass just 14′ from each other on the morning of March 3. The two can be glimpsed in the same telescopic field of view for several days before and after this conjunction.

### THE ARRIVAL OF SPRING

Spring begins in the Northern Hemisphere on March 20 when the Sun moves north of the celestial equator.

## Dates and Times

**2** Saturn passes 0.2° south of Neptune, 9 p.m. EST

**3** The Moon passes 5° south of Saturn, 1 a.m. EST

**4** Flora is at opposition

**5** The Moon passes 0.8° north of Mercury, 11 p.m. EST

**7** New Moon is at 1:19 p.m. EST; partial solar eclipse

**8** The Moon is at perigee (222,165 miles from Earth)

**12** Mars passes 2° north of Jupiter, 3 a.m. EST
The Moon passes 6° north of Jupiter, 2 p.m. EST
The Moon passes 4° north of Mars, 2 p.m. EST

**14** First Quarter Moon is at 5:11 a.m. EST

**15** Nemausa is at opposition

**19** The Moon passes 0.01° north of Regulus, noon EST

**20** Vernal equinox is at 10:28 a.m. EST

**22** Full Moon is at 4:58 a.m. EST
The Moon is at apogee (252,496 miles from Earth)

**27** The Moon passes 0.6° south of Antares, 9 p.m. EST

**28** Mars passes 7° north of Aldebaran, 1 p.m. EST

**30** Last Quarter Moon is at 5:21 a.m. EST
The Moon passes 5° south of Saturn, 11 a.m. EST

**Map Art by Wil Tirion**

# Eye on the Sky by Deborah Byrd

## PARTIAL ECLIPSE OVER WESTERN NORTH AMERICA

A partial eclipse of the Sun greets observers in Hawaii and the western half of North America on the morning of March 7. The greatest coverage occurs off the western coast of Alaska, where the Moon blots out more than four fifths of the Sun at maximum eclipse.

Although not the grand spectacle of a total solar eclipse — when the Moon passes directly in front of the Sun and the Moon's dark umbral shadow sweeps across Earth — a partial eclipse is fascinating nonetheless. In this month's eclipse the Moon's umbral shadow never reaches Earth's surface but instead swings less than four hundred miles above Alaska. If you're lucky enough to be in the lighter part of the Moon's shadow, called the penumbra, you can see a partial eclipse (the maximum depth depends on your exact location).

The first word in observing a solar eclipse is caution: *Do not look at the Sun directly*! The Sun's surface radiates so much energy that even the slimmest crescent can damage your eyes, perhaps permanently.

The safest and easiest way to observe an eclipse is to make your own "pinhole telescope." First, punch a small hole in a piece of cardboard. Then hold the cardboard so sunlight passes through the hole and on to a screen or sheet of white paper behind the cardboard. The resulting circle of light is an image of the Sun. (The image is small but gets proportionally larger as the distance between the hole and screen increases.) If the eclipse has already started, you'll see the Sun's disk with a chunk missing from one side — as though something has taken a bite out of it. The size of the missing piece grows as the eclipse progresses.

**MAXIMUMS OF SOLAR ECLIPSE**

| City | Local Time | Percent Covered |
|---|---|---|
| Albuquerque | 11:06 a.m. | 20 |
| Anchorage | 9:13 a.m. | 80 |
| Billings | 11:22 a.m. | 38 |
| Boise | 11:09 a.m. | 46 |
| Casper | 11:20 a.m. | 31 |
| Denver | 11:17 a.m. | 24 |
| Des Moines | 12:35 p.m. | 9 |
| Edmonton | 11:28 a.m. | 52 |
| Los Angeles | 9:50 a.m. | 36 |
| Portland | 10:05 a.m. | 56 |
| Rapid City | 11:26 a.m. | 28 |
| Salt Lake City | 11:10 a.m. | 36 |
| San Diego | 9:49 a.m. | 33 |
| San Francisco | 9:52 a.m. | 46 |
| Seattle | 10:10 a.m. | 57 |
| Vancouver | 10:12 a.m. | 59 |
| Winnipeg | 12:41 p.m. | 28 |

**WATCH THE SOLAR ECLIPSE** on the morning of March 7 and see up to 80 percent of the Sun covered by the Moon.

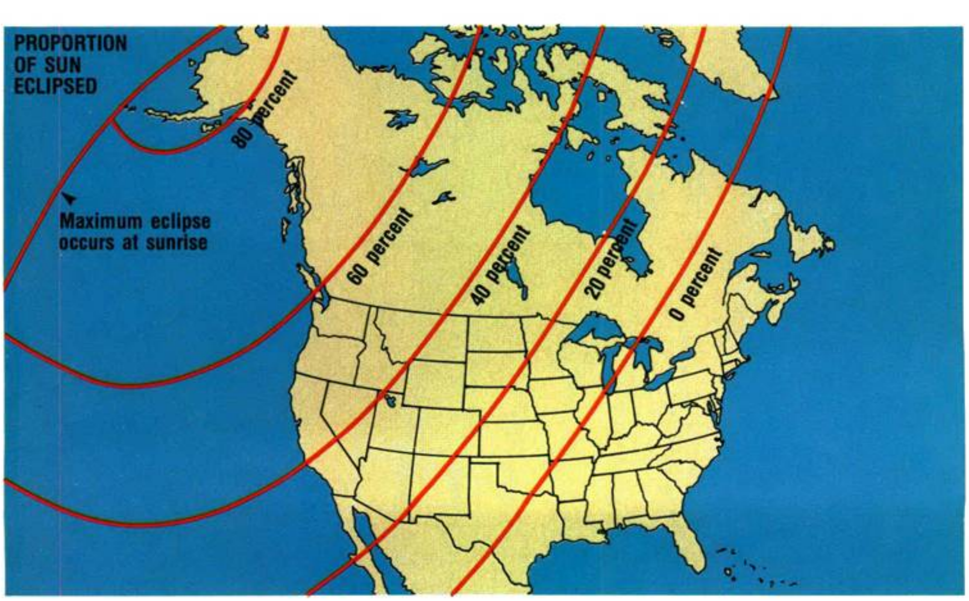
## MARS PASSES CLOSE TO JUPITER

A fascinating meeting of two planets occurs in the west after sunset this month as Mars sweeps close to Jupiter on the dome of the sky. Jupiter is easier to identify: it is the brightest starlike object in the sky at magnitude −2.2. Mars is much fainter at magnitude +1.1, but it is noticeable as the ruddy light near Jupiter in the days around March 11.

You can enjoy watching Jupiter and Mars all month, but keep a particularly close eye on them in the two weeks beginning March 5. Mars starts out lower in the west than Jupiter, but during that first week it passes Jupiter to appear higher in the west. On the evenings of March 10 and 11, Mars lies less than 2° from Jupiter and afterward climbs away from the brighter planet.

This event is all the more striking because of the planets' current location in the constellation Taurus. They appear sandwiched between Taurus's two eye-catching star clusters: the misty Pleiades, or Seven Sisters, and the V-shaped Hyades.

As the two planets make their close approach, the crescent Moon sweeps through this region of sky. It is especially striking near Jupiter, Mars, and the two star clusters on the evening of March 12.


PROPORTION OF SUN ECLIPSED

## AS DAY BECOMES LONGER THAN NIGHT

The March equinox occurs at 10:28 a.m. eastern standard time (7:28 a.m. PST) on March 20. At that instant the center of the Sun crosses the celestial equator, an imaginary line drawn around the sky directly above Earth's equator. On the day of the equinox the Sun appears directly overhead at noon to observers on the equator.

The word equinox means "equal night." Around March 20, days and nights are approximately equal in length. They're not precisely equal for several reasons. One is that the Sun is close enough to us that it appears as a disk, not as a point. The first sliver of this disk to come over the eastern horizon brings daylight, and night does not begin until the entire disk drops below the western horizon. Even at the equator this fact can lengthen the day by a minute or two. For latitudes in the United States the length of day and night is most nearly equal on March 16.

## MARCH'S PLANETS

Mars can be found in the west after sunset when the month begins. It is neither terribly bright nor conspicuous now, in marked contrast to its appearance just a few months ago. However, Mars is currently moving rapidly in front of the stars. You can detect this motion by noting its changing position against the background stars over the course of just two or three days.

Mars is closing fast on a much brighter planet in that part of the sky, Jupiter. On March 10 and 11 the two planets are located within 2° of each other on the celestial dome.

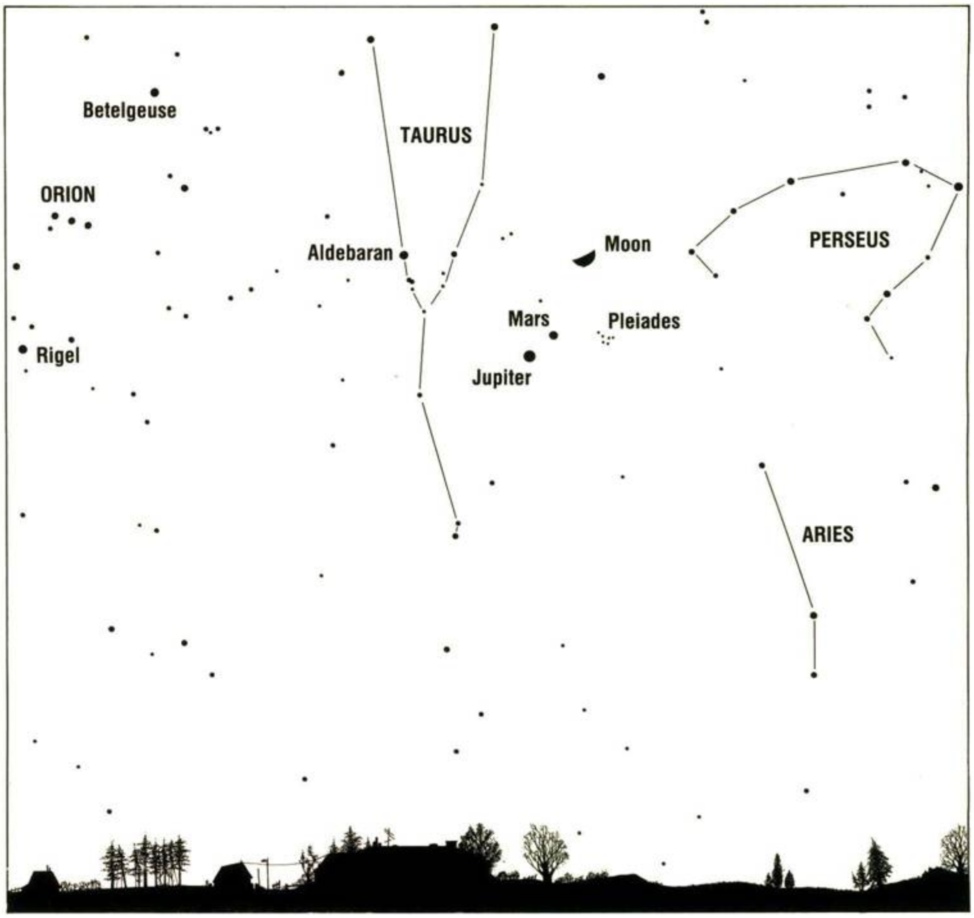
Although Mars is not terribly bright, it is still distinctive because of its orange color. There is another orange object located in this region of the sky, the bright star Aldebaran that forms the "eye" of the mythical bull Taurus. Mars passes 7° north of Aldebaran on March 28. On that night the star shines at magnitude 0.85, slightly brighter than the magnitude-1.3 Red Planet.

First Jupiter, then Aldebaran. Mars will continue rushing eastward in front of the stars over the next several months. Its rapid pace will keep it out of the Sun's glare until late summer. Jupiter, on the other hand, moves less swiftly toward the east. It will drop into the sunset glow and be lost from view in late May.

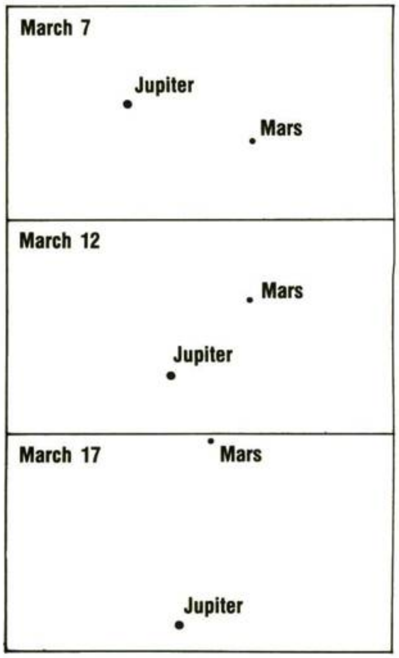
The morning sky holds the only other planet that can be glimpsed easily with the naked eye in March. Saturn rises when most of the world is asleep, about midway between midnight and dawn. At first light it lies low in the southeast, an inconspicuous dot of golden light near the "Teapot" asterism in the constellation Sagittarius.

Saturn will become more conspicuous as it approaches its July opposition, when Earth will pass between Saturn and the Sun. It's not hard to imagine why its brightness will increase. Since January when the planet first came out from behind the Sun and reappeared in our predawn sky, we have been catching up to the ringed planet in our smaller orbit around the Sun. Saturn's brightness increases as the distance between our two worlds decreases.

Yet the planet was fainter last month than it was in January, and it doesn't begin to brighten again until the middle of this month. Saturn's brightness in our sky depends on two things: its distance and the tilt of its rings as seen from Earth.



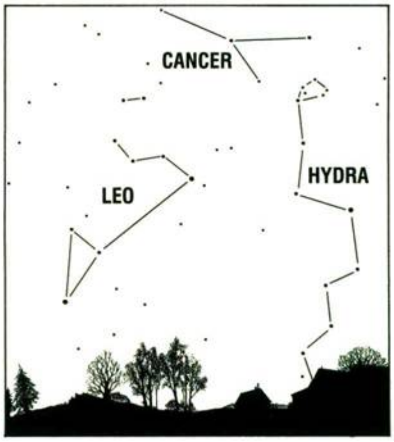
**MARS LIES CLOSE TO JUPITER** in the western evening sky this month. The Moon joins the pair on March 12 (above) when the two are 2° apart, but you can follow the planets' motions throughout the middle of March (below).



Last year Saturn's rings appeared very open to us. So far this year they have been slowly closing. When the rings are less open, less sunlight reflects from them and Saturn appears generally fainter. But even though the rings will continue to close until late April, the decreasing distance between Earth and Saturn wins out this month and the ringed planet begins to brighten imperceptibly.

The elusive planet Mercury lies in the predawn sky when March begins, but it's very close to the Sun. You might try looking for it on March 5 or 6, half an hour before sunrise, when Mercury is near the slim crescent Moon. (The planet is easier to see from the southern states.) Binoculars will help you to spot Mercury.

The predawn sky now seems empty without Venus. The brightest of all planets has at last disappeared into the glare of dawn, having fled far ahead of Earth in its smaller orbit around the Sun. It will pass behind the Sun in early April and return to the evening sky in May.



**LEO THE LION** rises majestically in the east on March evenings. The bright star Regulus lies at the bottom of Leo's sickle-shaped head and shoulders, while Denebola marks the tail of the lion.

## *MARCH'S STARRY SKY*

This month the eastern sky in the evening is empty of planets. Look instead for a harbinger of warmer months ahead, the constellation Leo the Lion.

A good time to look is the evening of March 19, when the nearly Full Moon appears below Regulus, Leo's brightest star. Beginning at Regulus and continuing up and to the left, trace the easily recognizable pattern of stars in the shape of a backwards question mark. This asterism in Leo is sometimes called the Sickle, and it represents the head and shoulders of the lion.

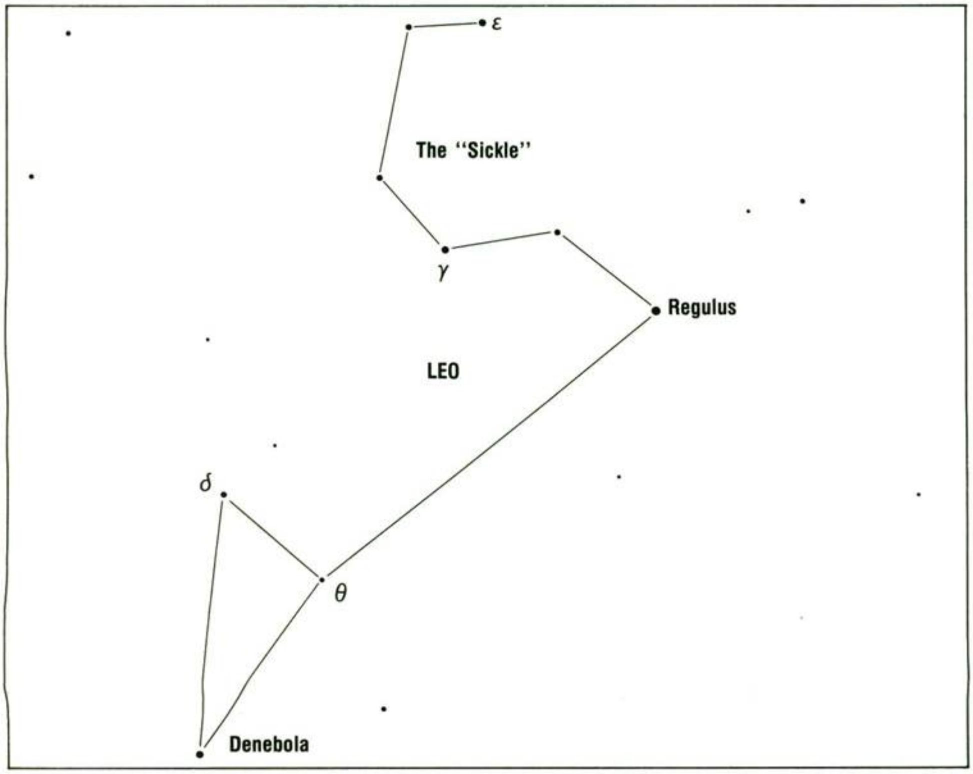
Regulus has the nickname Cor Leonis, meaning the "heart of the lion." This single point of light is really a triple star system located 85 light-years away.

The second-brightest star in Leo is not in the question mark asterism. It is Denebola, located in a prominent triangle of stars just to the east of the Sickle. The word "deneb" in a star name often means "tail." Denebola marks the tail of Leo.

This great lion in the sky is such a distinctive pattern that it has often been used by navigators as they attempted to find their way across the surface of Earth. In mythology, however, the lion is not depicted as being so benign. It supposedly sprang from the Moon in the form of a fiery meteor and landed on Earth in the Nemean valley of ancient Greece.

There the lion was greatly feared. It killed sheep and cattle, destroyed fields of grain, and generally terrified the people. What's more, its skin was said to be impenetrable: no arrow or spear could pierce it.

According to the myths, the Greek hero Hercules had to kill the Nemean lion as the first of his famous Twelve Labors. He managed to grasp the lion by the throat and crush the beast in his arms. Afterwards Hercules wore the lion's skin as protection against his enemies. And the lion was transported to the sky by Zeus in remembrance of Hercules' mighty deed. □



# Through the Eyepiece by Rick Shaffer

## SATURN AND NEPTUNE IN THE SAME FIELD OF VIEW

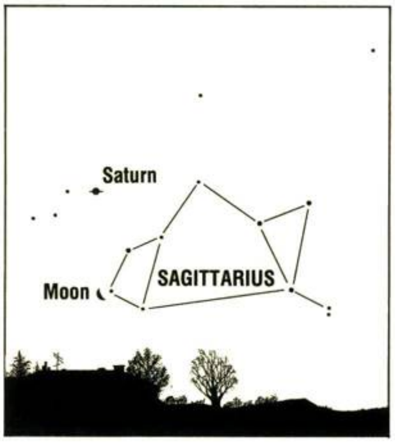
The best telescopic event in March is unquestionably the close conjunction of Saturn and Neptune. On the morning of March 3, Saturn passes a mere 14′ south of the much fainter and more distant planet Neptune, and both will be visible in the same field of view. The proximity of bright Saturn makes Neptune far easier to find this year than at any time in the recent past.

The two planets rise around 3:30 a.m. local time and are well placed about 15° above the southeast horizon at 5 a.m. Saturn, at magnitude 0.6, is the brightest starlike point in that part of the sky. On the morning of the 3rd, a slim crescent Moon in the Teapot asterism of Sagittarius lies just 5° below the planetary pair.

Once you've found Saturn in a low-power eyepiece, the trick is to identify Neptune. Although the 8th-magnitude planet is bright enough to see with almost any optical aid, it is much dimmer than Saturn and fainter even than 31 Sagittarii, a 6.7-magnitude star located some 4′ north of Neptune. The telescopic field at lower right will help you pinpoint Neptune. Examining what you've found at high power is the surest way to confirm Neptune's identity. The planet will appear blue-gray and sport a discernible 2.2″-diameter disk. Saturn, in contrast, will measure 16″ across and its rings will span 36″.

After examining Neptune, shift your telescope back to Saturn. In addition to its glorious rings, Saturn possesses a retinue of five bright satellites. The charts at the top of page 62 will help you locate the inner four bright satellites — Tethys (magnitude 10.3), Dione (10.4), Rhea (9.7), and Titan (8.4) — during the first nine days of March. The fifth bright satellite, Iapetus, orbits nearly three times as far from Saturn as Titan does and varies from magnitude 10.1 to 11.9 between western and eastern elongation. Use the charts to find Iapetus between March 2 and 9 as it passes north of Saturn's disk.

Although Saturn and Neptune appear closest on March 3, the two remain less than 1° apart for the first three weeks of the month. The pair remain close all year, and this month's event is just the first of three conjunctions between the two planets in 1989.

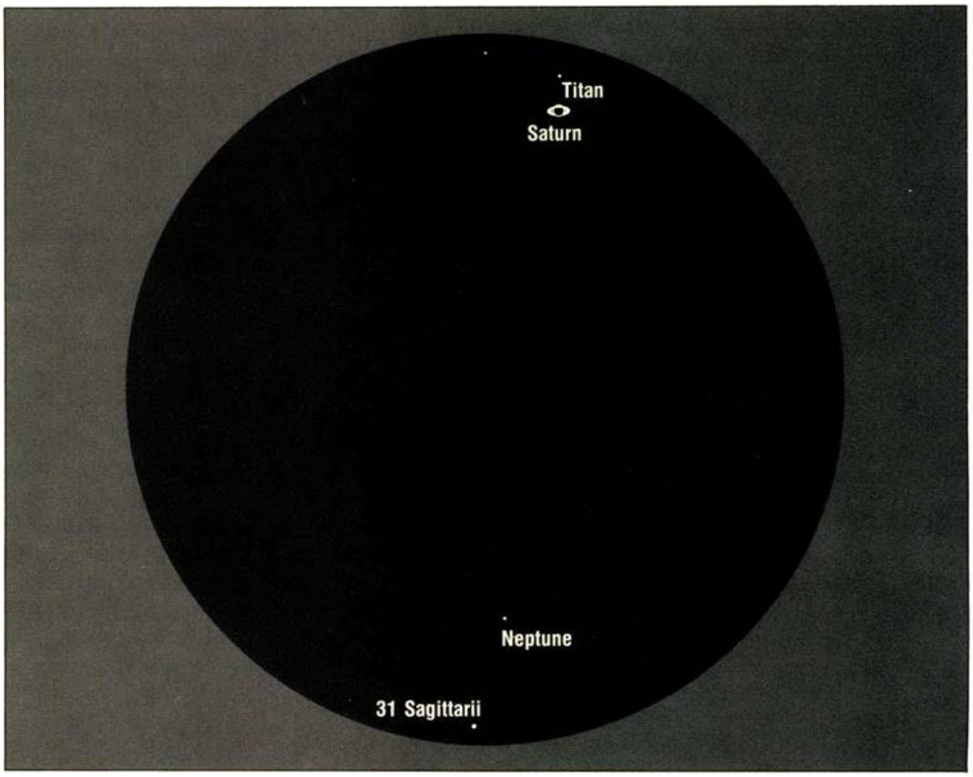


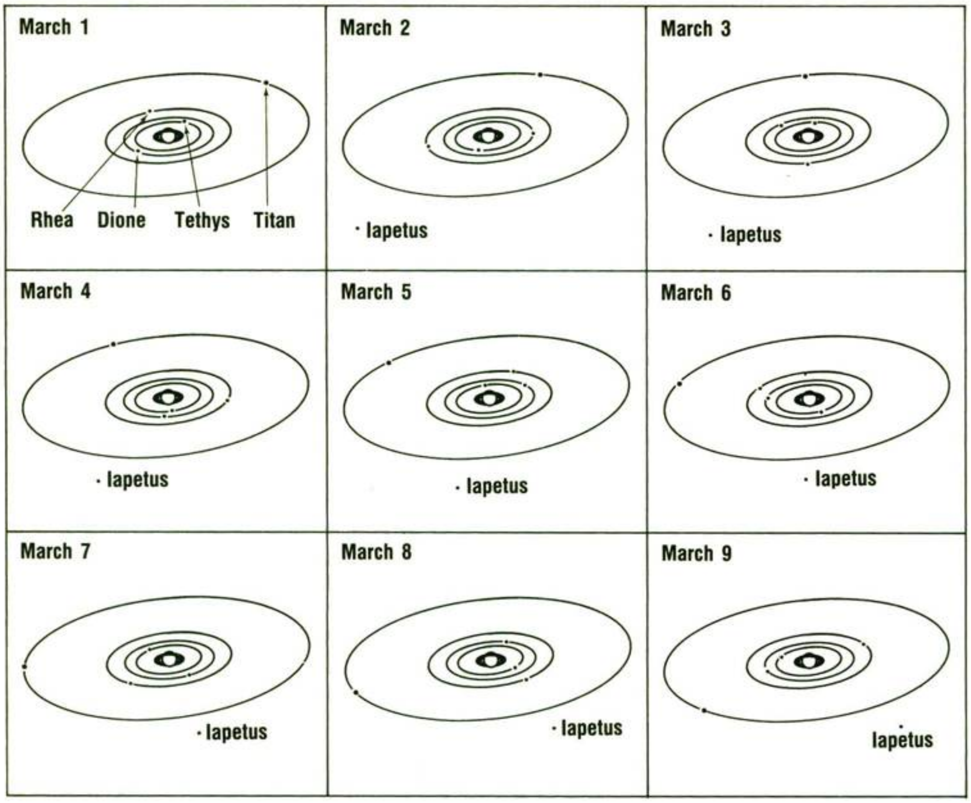
**SATURN AND NEPTUNE** pass 0.2° from each other in March. The two are just 5° above the Moon and low in the southeast as twilight begins on March 3 (above). Through an 8-inch f/6 Newtonian at 200x, the two appear in the same field of view (below).

## A COLORFUL CONTRAST

On the night of March 11/12, Mars passes 2° north of Jupiter. Not just for naked-eye observers, this event is interesting for telescope owners as well because of the difference in the colors of the two planets.

The best time for North American observers to view the pair is on the evening of March 11 when both objects have nearly the same right ascension. Unfortunately the separation between Mars and Jupiter is too great to view both planets in the same field at a power high enough to resolve their disks. However, the two are close enough for you to easily shift from one to the other. An equatorial telescope is superior for this purpose because the motion is entirely in declination. Those with altazimuth telescopes must use both the altitude and azimuth controls to move the telescope back and forth.

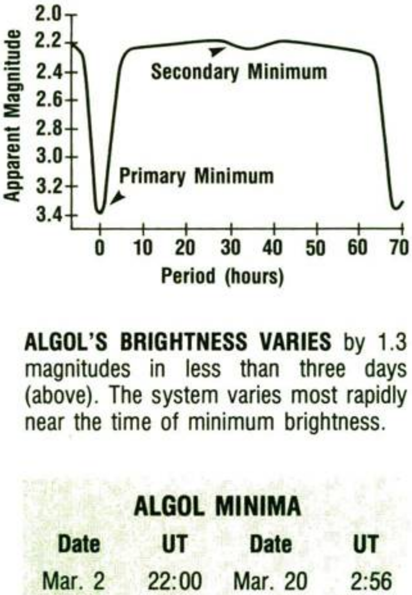




**SATURN'S MOONS** are easy to see if you know where to look. These drawings show the five brightest satellites at 11 UT (6 a.m. EST, 3 a.m. PST).

As you compare the two planets, notice the color contrast between the ocher disk of Mars and the white to slightly yellow zones between Jupiter's belts. A more significant comparison is between the brown of the Jovian belts and the color of the dark markings on Mars. Although the Martian markings frequently appear dark green, this seems to be a perception effect created because the markings are superimposed on the ocher of the rest of the planet. It's the combination of our eye and brain that interprets their color as dark green — the markings are actually gray-brown. Once you see the brown of the Jovian belts and then switch rapidly to Mars, do the dark markings appear more gray-brown than green? Try it and see.

You can use the same technique to compare the apparent sizes of celestial objects with your telescope. The second week of March is an excellent time, because Mars passes 3° south of the Pleiades star cluster (M45) while remaining close to Jupiter. Use your lowest-power eyepiece and move your telescope among the Pleiades, Mars, and Jupiter. First compare the tiny, 6″-diameter Mars to the 37″-diameter Jupiter. Despite looming six times larger, Jupiter is less than one third the size it would be at Mars' distance because it is more than three times farther from Earth than Mars. Now compare the Pleiades to the size of Jupiter's system of Galilean satellites. The separation between Jupiter and Callisto, the outermost satellite, subtends an angle of roughly 0.1° when Callisto is farthest from Jupiter, while the Pleiades subtend an angle of nearly 2°. The cluster, actually about 13 light-years in diameter, appears to be only ten to twenty times larger than the Jovian system because it lies 5 million times farther away!



**ALGOL'S BRIGHTNESS VARIES** by 1.3 magnitudes in less than three days (above). The system varies most rapidly near the time of minimum brightness.

**ALGOL MINIMA**

| Date | UT | Date | UT |
|---|---|---|---|
| Mar. 2 | 22:00 | Mar. 20 | 2:56 |
| Mar. 5 | 18:49 | Mar. 22 | 23:45 |
| Mar. 8 | 15:39 | Mar. 25 | 20:34 |
| Mar. 11 | 12:28 | Mar. 28 | 17:23 |
| Mar. 14 | 9:17 | Mar. 30 | 14:13 |
| Mar. 17 | 6:06 | | |

To convert from UT to local time, subtract 5 hours for EST and 8 for PST.

## *FROM A WONDERFUL TO A DEMON STAR*

March is the first month in which you need some optical aid to view Mira, the pulsating variable star in Cetus. Early in the month Mira should be about halfway from maximum to minimum brightness — at about magnitude 6.5 if it's behaving according to its standard light curve.

This is a good month to split your time between Mira and another famous variable star, Algol, or Beta ($\beta$) Persei. Also known as the "Demon Star," Algol is the second-brightest star in Perseus and can be found in the northwest on March evenings. (The map in the center of the magazine will help you to find it.) It is apparently called the Demon because its brightness variations are easily visible to the naked eye.

Algol's brightness varies by a factor of just over three, from about magnitude 2.1 to 3.4. It takes Algol 2 days, 20 hours, and 49 minutes to undergo one complete cycle of variation, a far cry from the 332-day period of Mira. Because of this short period, you can fashion a decent light curve for Algol from a month's worth of observations with your eye, binoculars, or a small telescope.

Algol's light curve is shown at left, along with a table listing the times this month when Algol is at minimum brightness. As you can see, Algol varies most rapidly around the time of minimum. If you are mainly interested in seeing Algol change brightness, observing the star for a couple of hours near minimum light should be enough. If you are more interested in tracking the entire cycle, you should observe Algol without knowing its predicted magnitude ahead of time, because that can compromise your objectivity.

Algol has a regular variation because it is an eclipsing binary system. A bright star and a fainter companion orbit each other nearly in our line of sight, so each eclipses the other once each orbit. When the dimmer companion passes between us and the brighter primary star, it blocks about 80 percent of the light from the primary and substitutes its own relatively feeble light. For most of the rest of one orbit, the light we see is the combined light from both stars. When the companion passes behind the primary, the primary blocks about 80 percent of the companion's light, which accounts for the shallow secondary minimum in the light curve.

**A PARTIAL ECLIPSE,** like the one on March 7, is a great chance to take stunning photos. Diego Meozzi captured a 58 percent eclipsed Sun on May 30, 1984.

## *TELESCOPIC PLANETS*

The shadow of Earth's Moon crosses western North America on March 7, and observers there can see a partial solar eclipse. Although a partial eclipse lacks the grandeur of a total eclipse, photographing the eclipsed Sun is still an interesting project. You can use either the eyepiece-projection method and photograph the projected solar image or use an over-the-aperture solar filter and shoot directly through the telescope. In either case make sure to cap your finder scope and *never* look directly at the Sun. The map on page 58 shows how much of the Sun is eclipsed for different locations in North America.

Mercury was difficult to observe in morning twilight during February's apparition, and it is nearly impossible to observe this month. You might try looking for Mercury in daylight early in March using the methods I presented in last month's column. Make sure to cap your finder and to avoid pointing your unprotected telescope toward the Sun. Observers in East Africa and Asia can see Mercury occulted by the almost New Moon early on March 6.

Venus rises fifteen minutes before the Sun at the beginning of March and is essentially lost from view. You might give daytime viewing a shot, but follow the same safety precautions given for observing Mercury.

Early morning observers have a fine trio of planets — Saturn, Uranus, and Neptune — to view this month. Located in Sagittarius, the three rise approximately four hours before the Sun on March 15 and are above much of the horizon murk as twilight begins.

## *ASTEROIDS IN THE EYEPIECE*

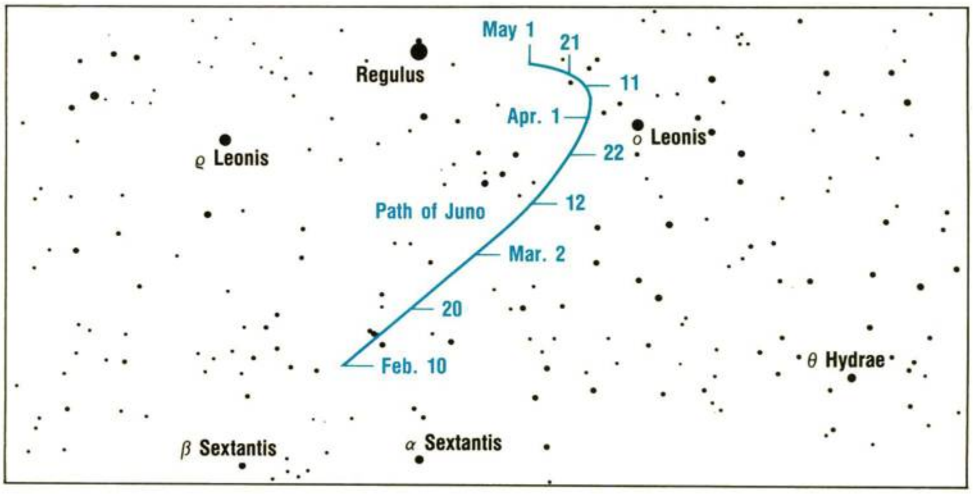
March features several bright asteroids for your viewing pleasure. Ninth-magnitude 3 Juno, which reached opposition on February 20, passes from Sextans into Leo this month. Use the finder chart or table of coordinates at right to locate Juno's approximate position and then observe that area at low power and photograph or sketch what you see. Observe the same area a night or two later and look for a point of light that has changed position. That is Juno.

In addition to Juno, 7 Iris remains a bright object in Cancer and can be found with the map in February's Through the Eyepiece. In March two more major asteroids reach opposition — 8 Flora shines in Leo at magnitude 9.3 on the night of March 3/4 and 51 Nemausa shines at magnitude 9.6 on March 15 in Virgo. ☐

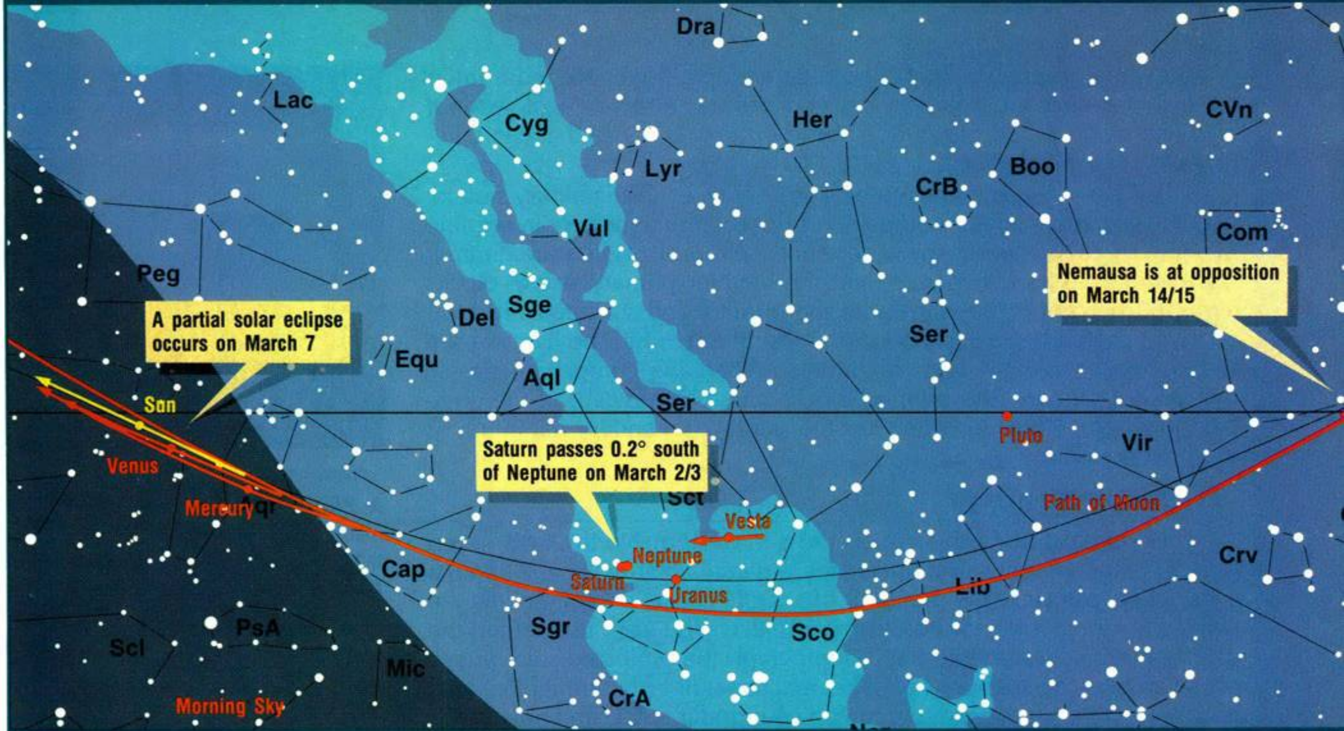
**COORDINATES FOR JUNO**

| Date | R.A. (2000) | Dec. |
|---|---|---|
| Feb. 10 | 10h17.8m | 2°30′ |
| Feb. 20 | 10h09.5m | 4°09′ |
| Mar. 2 | 10h01.4m | 5°53′ |
| Mar. 12 | 9h54.6m | 7°31′ |
| Mar. 22 | 9h49.9m | 8°57′ |
| Apr. 1 | 9h47.6m | 10°07′ |
| Apr. 11 | 9h47.8m | 10°58′ |
| Apr. 21 | 9h50.4m | 11°31′ |
| May 1 | 9h55.2m | 11°47′ |

**OBSERVE ASTEROID 3 JUNO** as it moves from Sextans into Leo, southwest of 1st-magnitude Regulus. (Positions are given for 0 UT.)



# The Solar System March 1989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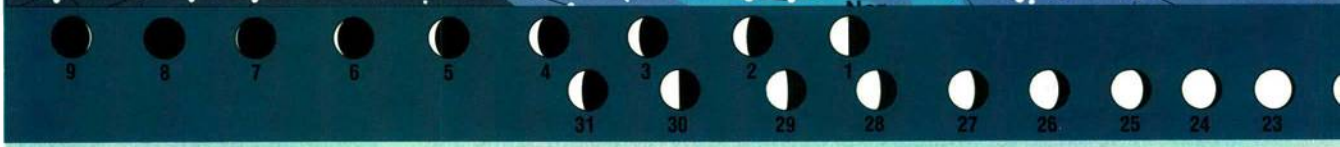
Equ
Aql
Ser
Sun
Pluto
Vir
Venus
Sct
Vesta
Mercury
Aqr
Path of Moon
Neptune
Cap
Saturn
Uranus
Lib
Crv
PsA
Sgr
Sco
Scl
Mic
CrA
Morning Sky

A partial solar eclipse occurs on March 7

Saturn passes 0.2° south of Neptune on March 2/3

Nemausa is at opposition on March 14/15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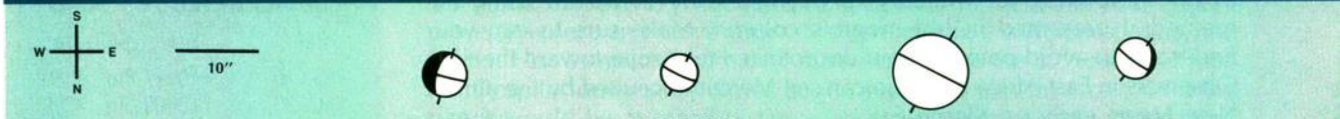
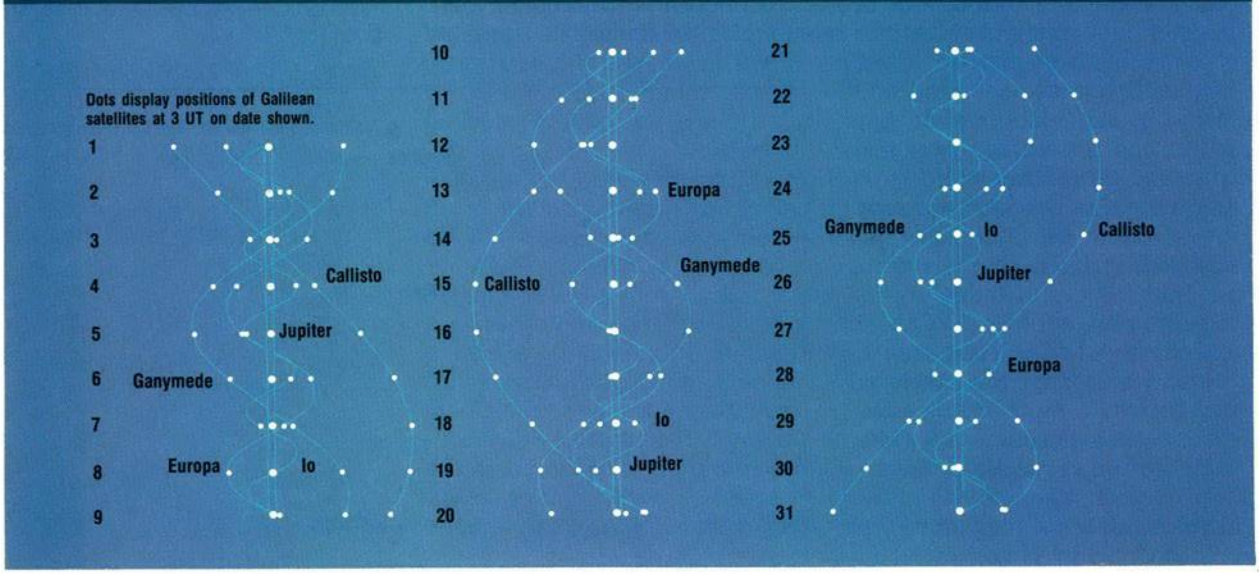
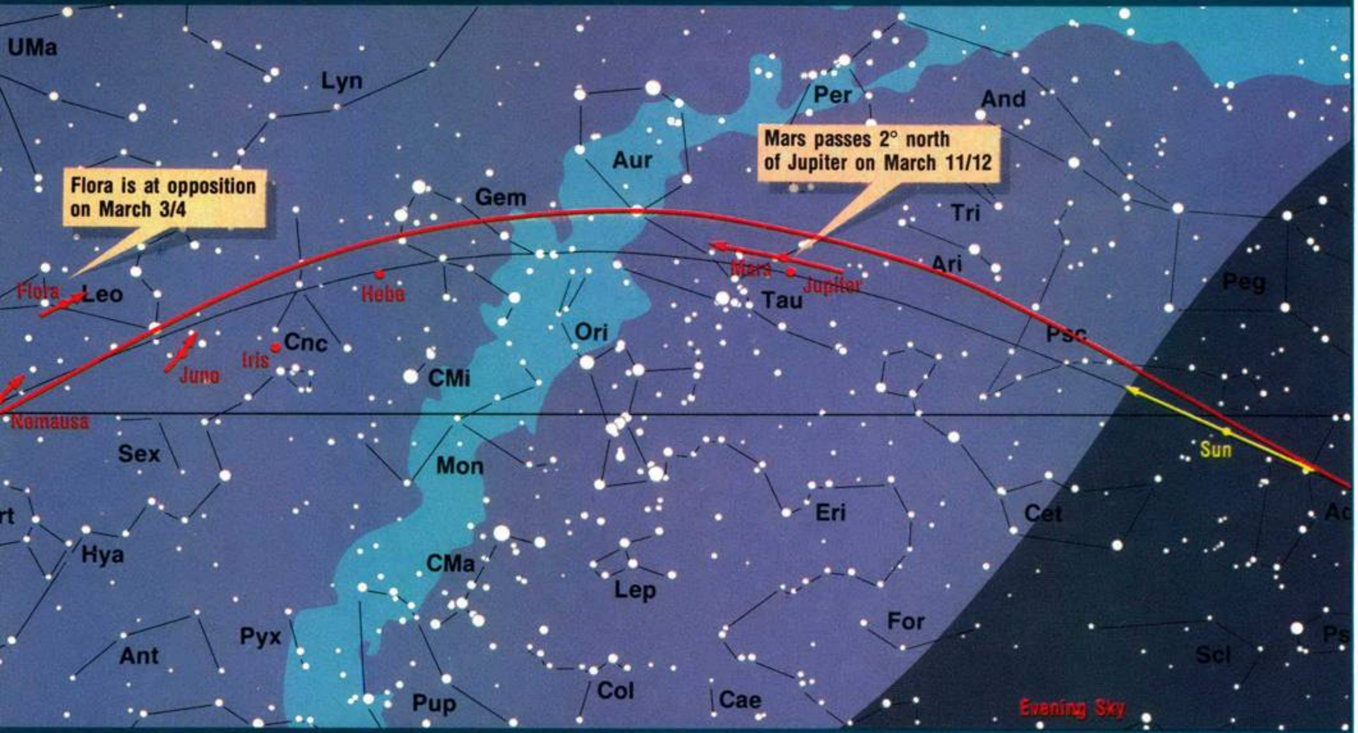


| Planet | MERCURY | MERCURY | VENUS | MARS |
|---|---|---|---|---|
| Date | March 1 | March 31 | March 15 | March 15 |
| Magnitude | 0.0 | −1.5 | −3.9 | +1.2 |
| Angular Size | 6.00″ | 4.99″ | 9.8″ | 5.6″ |
| Illumination | 74% | 99% | 100% | 91% |
| Distance (AU) from Earth | 1.121 | 1.349 | 1.711 | 1.670 |
| Distance (AU) from Sun | 0.467 | 0.364 | 0.728 | 1.589 |
| Right Ascension (2000.0) | 21h15.5m | 0h23.4m | 23h22.7m | 4h00.0m |
| Declination (2000.0) | −17°15′ | 0°50′ | −5°35′ | 21°55′ |

## Jupiter's Moons




UMa
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Ari
Flora
Leo
Hebe
Mars
Jupiter
Tau
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Juno
CMi
Ori
Psc
Nemausa
Sex
Mon
Sun
Eri
Cet
Hya
CMa
Lep
For
Ant
Pyx
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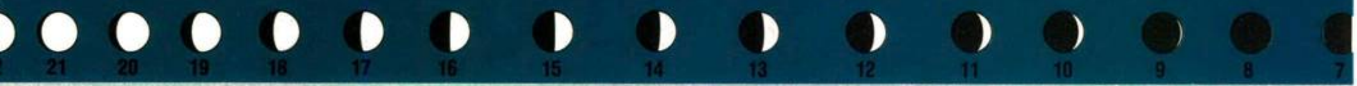
Cae
Pup
Evening Sky

Flora is at opposition on March 3/4

Mars passes 2° north of Jupiter on March 11/12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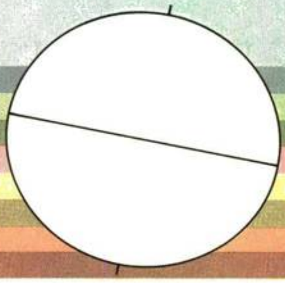
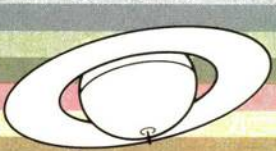
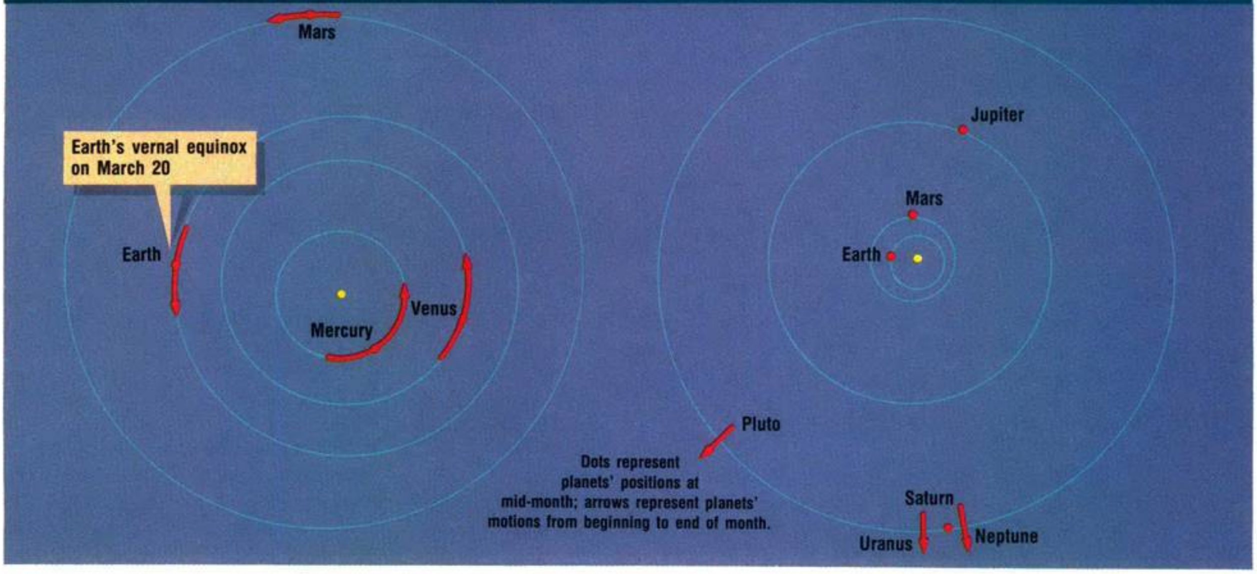




| JUPITER | SATURN | URANUS | NEPTUNE | PLUTO |
|---|---|---|---|---|
| March 15 | March 15 | March 15 | March 15 | March 15 |
| −2.2 | +0.6 | +5.7 | +8.0 | +13.7 |
| 36.7″ | 16.0″ | 3.6″ | 2.2″ | 0.1″ |
| 99% | 100% | 100% | 100% | 100% |
| 5.372 | 10.310 | 19.487 | 30.506 | 29.040 |
| 5.053 | 10.042 | 19.328 | 30.218 | 29.657 |
| 3h54.8m | 18h55.6m | 18h22.7m | 18h53.1m | 15h09.3m |
| 19°43′ | −22°09′ | −23°35′ | −21°58′ | −0°53′ |

## The Planets in Their Orbits


Mars
Earth
Mercury
Venus
Jupiter
Mars
Earth
Pluto
Saturn
Uranus
Neptune

Earth's vernal equinox on March 20

Dots represent planets' positions at mid-month; arrows represent planets' motions from beginning to end of month.

# Eight Lunar Wonders

Investigate eight geological oddities on the Moon and ponder the mysteries of their formation.

by Michael T. Kitt

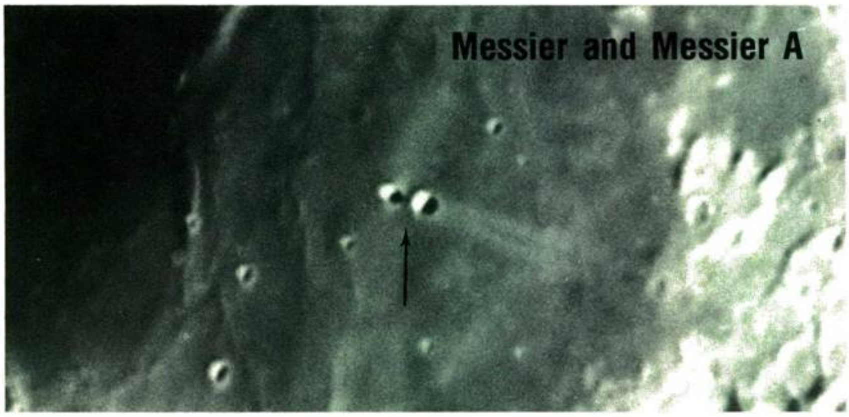
By its very nature a geological "wonder" is something out of the ordinary, someplace special that's worth a detour to go and see. But when astronomers first turned their telescopes toward the Moon, they saw mainly the ordinary things that make up the lunar world — mountains, dark plains, and thousands and thousands of craters. Lunar scenes didn't look too much like Earth's, but once astronomers grew accustomed to the sights, the Moon's features began to exhibit a sameness.

For instance, everywhere they looked crater was piled upon crater, and despite certain variations in size and form, one looked pretty much like another. The vast dark plains called "seas" — the maria — also didn't have much to differentiate them. The Moon, it seemed, was a stark, dead world of black, white, and gray.

But as time went on, observers who focused their telescopes a little more carefully noticed that there was more in the Moon's geological inventory than just mountains, plains, and craters. Sharp-eyed explorers at the eyepiece saw many odd features — formations that fit no obvious pattern. Because they were unusual, these features were often suspected of having evolved. Many lunar astronomers looked to them for evidence that the Moon was actively undergoing geological changes, as Earth does.

While those hopes were dashed by the results of the American and Soviet Moon programs of the 1960s, these lunar wonders are just as intriguing, mysterious, and uniquely beautiful as they ever were. And every month they return to view.

To explore some of these wonders, all you need is a telescope, eyepieces that yield 100x to 300x, and a clear night with good seeing. We'll start with a crescent Moon a few nights after New and greet each feature as it emerges from the long lunar night.



Messier and Messier A

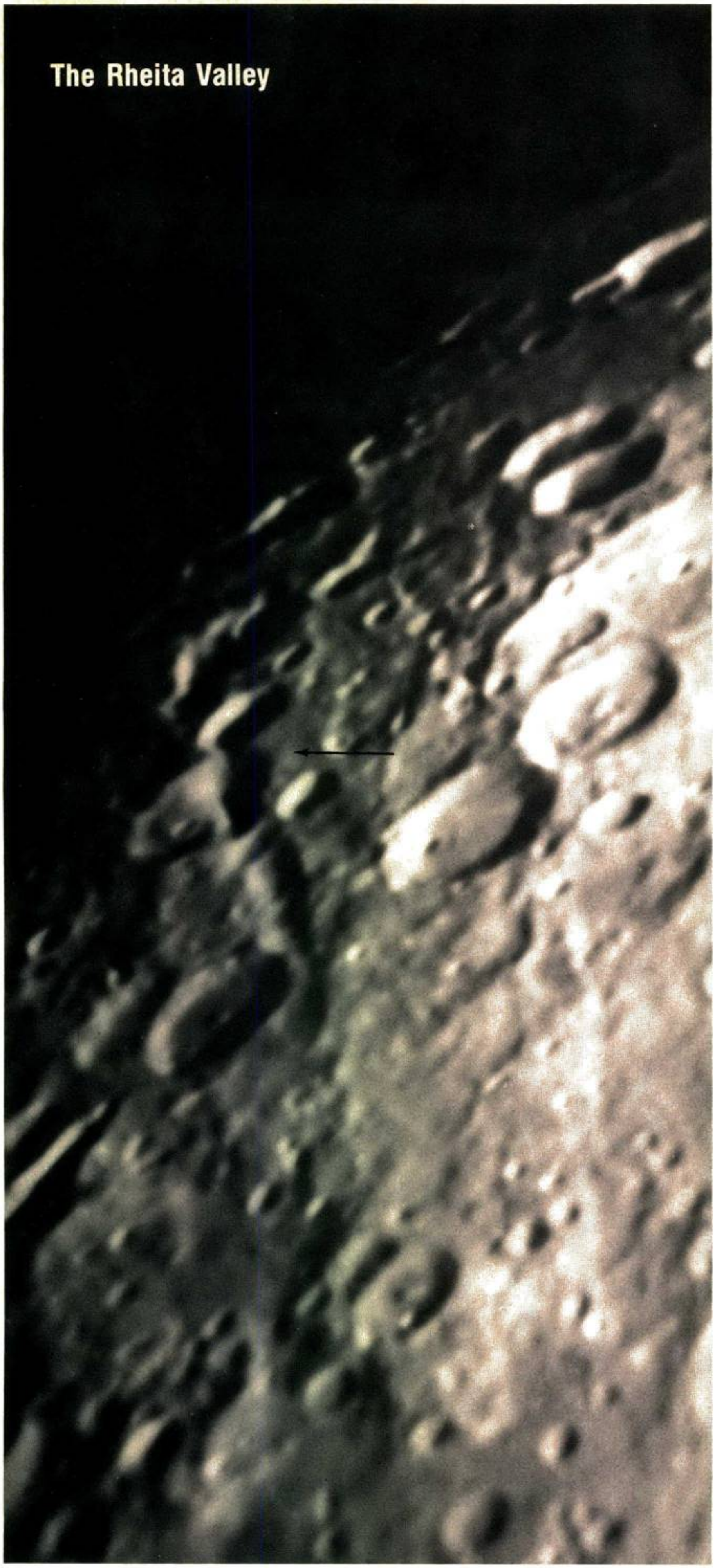
## Messier, the 'Comet Crater'

In the western plains of Mare Fecunditatis lies a well-known and much-studied pair of craters, Messier (the more eastern of the two) and Messier A. Though they are small, these two craters are highly distinctive and easy to find: two bright, slightly divergent rays radiate westward from the craters and make the formation look unmistakably like a comet caught in flight across the face of the Moon. No other feature, on the near side or far side, looks like this pair.

The Messier craters become visible the third night after New Moon. Messier is distinctly elongated (5 by 7 miles), while Messier A appears more circular (7 by 8 miles). The floor in both is noticeably darker than the inside walls. Messier A is actually a double crater with a rounder eastern half that looks brighter. It can look triangular under grazing illumination or when the seeing isn't steady. If you view the craters over three or four consecutive nights, the play of shadows in their interiors will alter the shapes of the craters considerably — and the longer you look at them, the more you'll wonder how to account for their appearance.

Many theories have been proposed to explain these craters. Messier A was thought to result from the impact of two meteors traveling side by side. In a more bizarre explanation one observer claimed in 1952 that the two craters might be connected by an underground tunnel, drilled by a meteor plunging into a ridge in the mare and bouncing out. Other lunar geographers, trying to understand early observations, saw the pair as evidence of active volcanism.

Today, thanks to laboratory studies and high-resolution photographs from lunar orbit, we know Messier was formed by the grazing impact of a small, westward-traveling meteor that hit the surface at an angle of about 5°. Messier A was formed when the projectile skipped and hit the lunar surface a second and perhaps a third time. Both impacts created elongated twin craters about 7 miles long in the longer axis, and the double ray formed when the second impact squirted out finely pulverized rock.



# The Rheita Valley

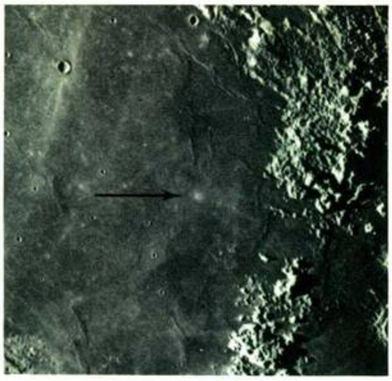
Also visible three days after New Moon is the Rheita Valley. It lies southeast of Mare Nectaris in a jumbled area of the Southern Highland littered with ancient craters. The valley, which at local sunrise looks like a wide black line running southeast, resembles a chain of craters with broken-down walls between them. One oblong hole overlaps the next to create a valley more than 100 miles long, about 15 miles wide, and roughly 2,000 feet deep. If you include a poorly defined extension that angles away from its southern end, the valley stretches over 200 miles.

It begins in the north at its namesake crater, Rheita. Because the valley is shallow, its irregular sides and buckled floor are especially interesting under low-angle illumination, which occurs either at sunrise or sunset (a couple days after Full Moon). In two places close together you can see where rocky ridges cut across the floor, breaking its length.

Although three or four similar formations exist on the near side of the Moon, they are indistinct and located near the limb of the Moon, where it is difficult to discern their true nature. The Rheita Valley, on the other hand, is difficult to miss and intriguing to explore, although it becomes relatively hard to see clearly when the Sun illuminates it from a high angle.

For over a century selenologists thought volcanism was the dominant force shaping the Moon's surface. Therefore they saw the Rheita Valley as a chain of volcanic calderas aligned along a massive fault radial to Mare Nectaris. But by the time spacecraft were taking close-ups of the Moon, most lunar geologists had adopted a model that interpreted lunar land forms as the result of impacts.

This was reinforced in part about twenty years ago when *Lunar Orbiter* photographs provided overhead views of the lunar far side's Mare Orientale and the enormous crater Schroedinger. Both formations possess radial valleys even larger than the Rheita Valley. Selenologists now think valleys such as these are huge gouge marks, scooped out by blocks of material ejected during the massive impacts that created Mare Nectaris and Mare Orientale.



# 'Vanishing' Linne

No object on the Moon has caused more controversy than the small crater Linne, which emerges at sunrise five days after New Moon. Ordinarily a crater the size of Linne — a mile and a half across — is hard to see. But finding Linne is easy because an apron of light-colored material surrounds the crater and extends outward at least 3 miles in all directions. Just look for the only small, bright white spot in west-central Mare Serenitatis.

At sunrise or sunset, Linne is just a very small circular object rising slightly above the mare surface, and high magnification and good seeing show Linne to be a tiny pockmark. Then, as the Sun's altitude increases and "turns on" the bright surrounding material, Linne undergoes a remarkable transformation: the light material grows dazzlingly bright and all but conceals the tiny crater.

Linne's dramatic variations in appearance led more than one nineteenth- and early twentieth-century astronomer to proclaim that Linne had undergone geologic changes that proved the Moon was volcanically active. Indeed, until the 1960s, it was still possible to think that the venting of volcanic gases might cause periodic changes in the shape of Linne's bright nimbus. Accordingly the crater was targeted for *Lunar Orbiter* photography.

Those detailed photos clearly showed Linne to be nothing more than an extremely fresh impact crater with a very bright halo of powdered rock around it. There isn't the slightest hint of volcanic activity, past or present; in fact, Linne could be a textbook small impact crater.

Nonetheless, as you observe Linne over several nights, you can marvel at the extent of its apparent changes and understand how so many observers of yesteryear went astray.

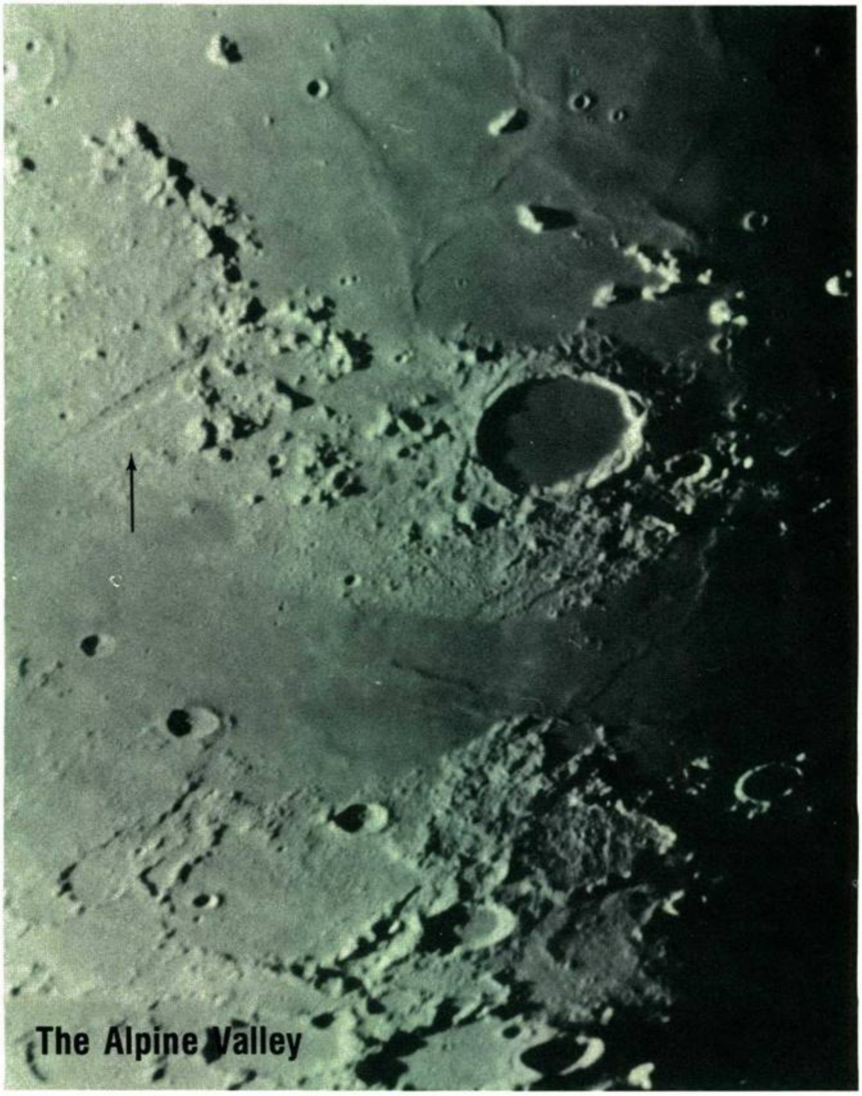
# The Alpine Valley

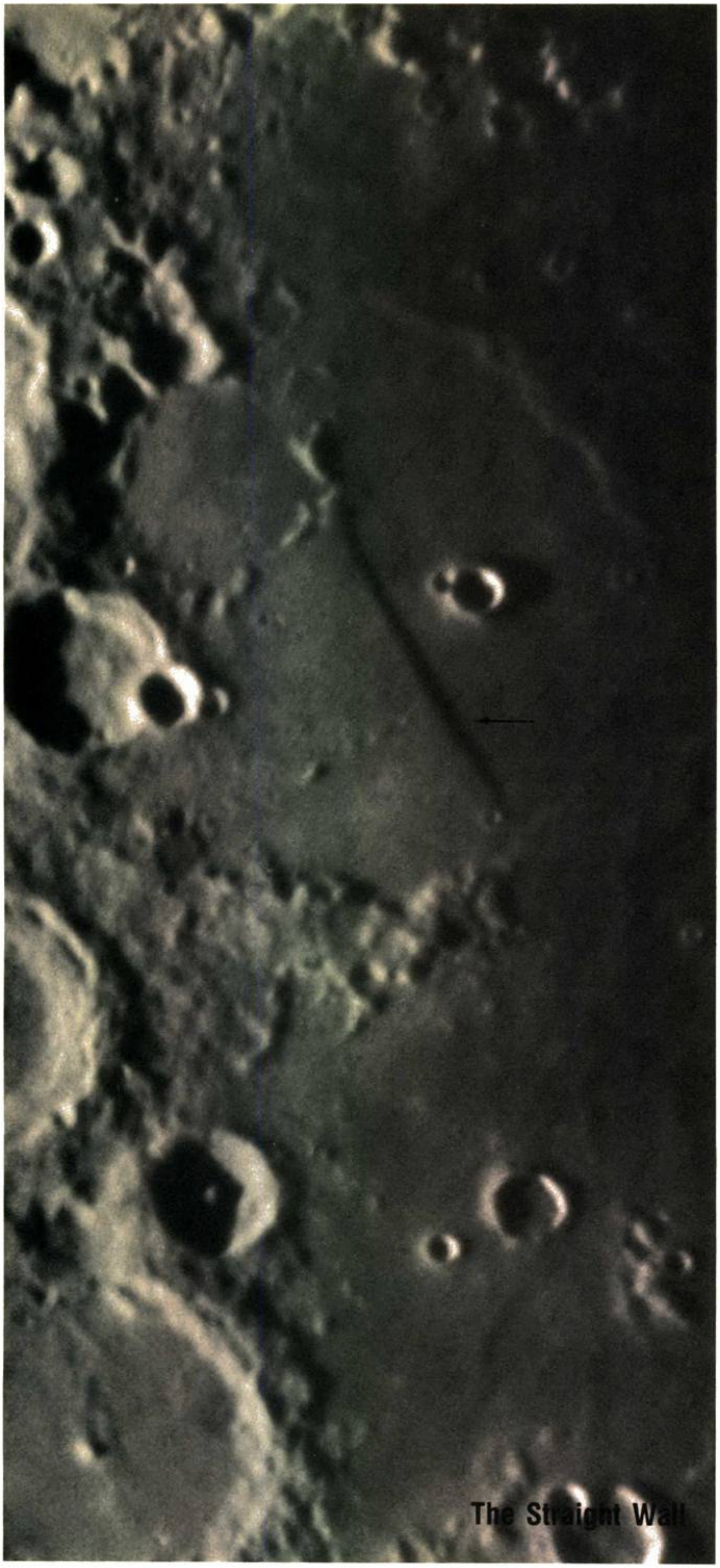
The Alpine Valley, in the lunar Alps on the northeast edge of Mare Imbrium, is one of the most attractive formations on the Moon. Less than a day after First Quarter, it is visible as a dark streak that cuts through the mountainous mass near the dark-floored crater Plato.

This valley has no exact counterpart on the Moon: neither the far side nor the near has anything closely resembling this gigantic valley that stretches some 80 miles. Its appearance has fostered much speculation over the valley's formation and its geological significance. Does it mark a grazing near-collision with a meteor? Or perhaps a chain of volcanic calderas? Or maybe even the track of some ancient lunar glacier?

Lunar scientists now believe the Alpine Valley is a graben — a swath of land dropped between two roughly parallel faults. A very thin, sinuous rille snakes down its middle, visible only through large instruments (12-inch or larger) under superb viewing conditions. This rille is a collapsed lava tube, the source of the flow that repaved the floor of the graben and gave it the smooth appearance it now has.

Where did the faults that border the graben come from? These fractures in the lunar crust most likely occurred during the great Moon-shaking impact that created Mare Imbrium 3.9 billion years ago. The valley is not the only sign left of this event: explore elsewhere in the Alps and the neighboring Apennines to the south and you'll see many linear features in the terrain lying radial to Mare Imbrium. These scars run for hundreds of miles.





# The Straight Wall

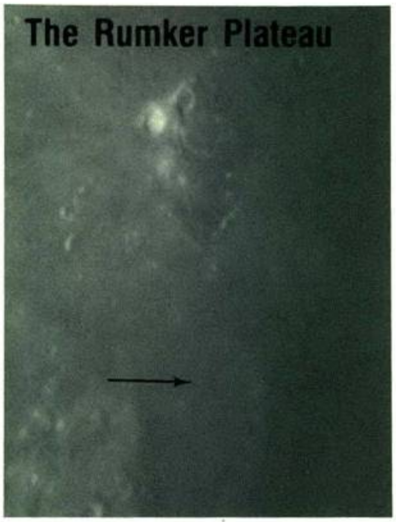
Soon after First Quarter, a renowned lunar feature comes into view south of the Moon's equator: the Straight Wall. It lies on the eastern edge of Mare Nubium near the small but prominent crater Birt. It is the Moon's most remarkable fault scarp.

The fault runs north-northwest to south-southeast. The eastern side is higher, so at First Quarter the Wall itself is dark and can be found by the wide shadow it casts on its downthrown side. This shadow is visible in even the smallest telescope at low to medium power — if you catch the Wall right at local sunrise. But as the Sun rises, the wide shadow of the scarp shrinks quickly until only a day after sunrise it is all but gone.

The Straight Wall remains visible during most of the lunar day (except when all terrain details are washed out at Full). But most of the time you'll need medium magnifications to see it easily. This is especially important if you are viewing with a small instrument (for instance, a 2-inch refractor or a 4-inch reflector). By the time Last Quarter rolls around and the Wall is lit by the setting Sun, it stands out as a thin white line and is seen most easily with medium to high magnifications.

A careful look reveals that the Straight Wall is neither straight nor is it a wall. In fact, it is one of only three known thrust faults on the Moon, places where the land on one side of the fault has been shoved on top of the land on the other side. Although the Straight Wall runs for over 70 miles, it is only 800 feet or so high and its slopes average just about 10 percent — hardly the towering cliff depicted in some pre-*Apollo* views of the lunar surface!

Lunar geologists are not certain about its origin, but as you look at it in the grazing light of sunrise or sunset, notice how it nearly bisects an old and extremely degraded circular structure. This "ghost crater" is most likely the remnant of a highly altered impact feature that was flooded almost to oblivion when the lavas oozed out to form Mare Nubium. (Similar structures can be found in every lunar sea.) As the lava cooled and settled, the surface under the old crater's center may have given way, buckling one lava sheet over another.

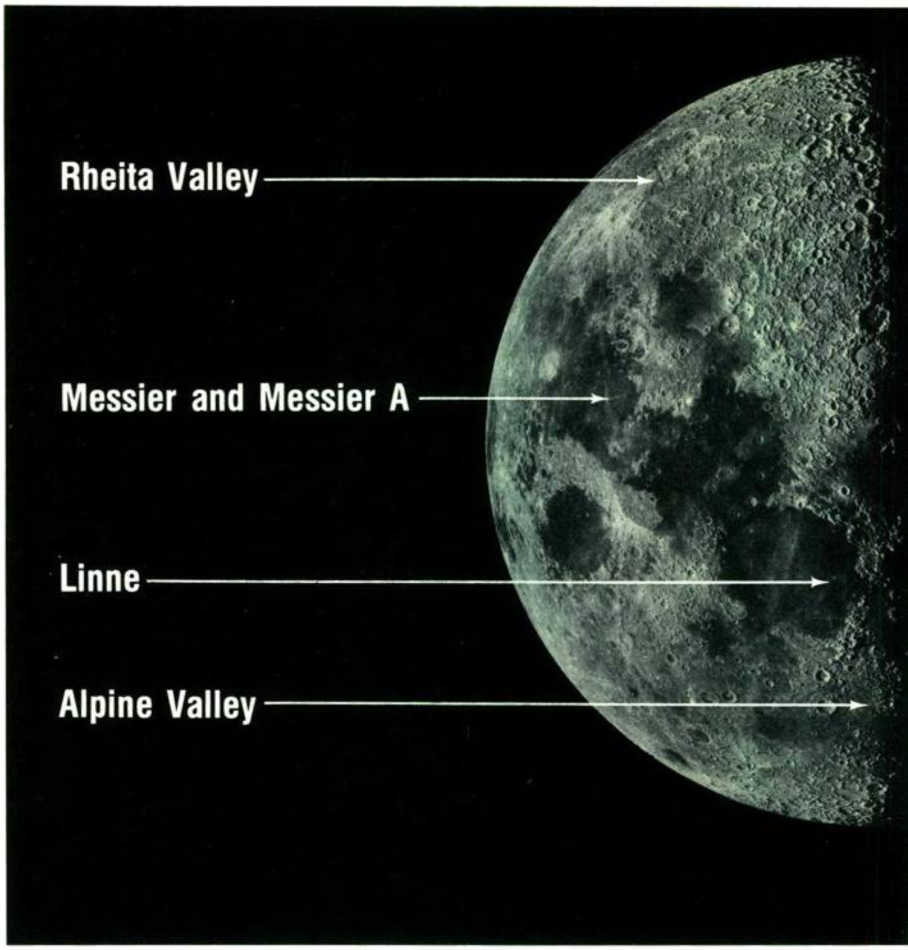


# The Rumker Plateau

You must wait until the Moon is twelve days old (nearly Full) to observe our final three objects. The first of them, the Rumker plateau, lies far to the north in the empty stretches of Sinus Roris, a small "bay" connecting Mare Frigoris with Oceanus Procellarum. Located due west of magnificent Sinus Iridum, the Bay of Rainbows, Rumker is a solitary complex of domes about 35 miles across.

Lunar domes are small, gently sloping volcanic hills, sometimes topped with a tiny vent crater. They are similar to terrestrial shield volcanoes (such as Hawaii) and occur in the lunar seas. Most are isolated, but occasionally they are found in small groups, as in the case of six or seven clustered just north of the crater Hortensius in eastern Oceanus Procellarum. In one place near the crater Marius located due west of Hortensius you can see a large field strewn with hundreds of small domes.

But Rumker is unique because it's the only example of domes clustered on top of domes, like some kind of giant lava blister. Domes have little relief, so they can be observed only when the terminator is passing over the formation and the low Sun angle throws long shadows behind every little hillock. Use high magnification *to bring* the rumpled surface of Rumker into focus. How many vent craterlets can you see? Imagine what this innocuous bump would have looked like at birth — with lava fire-fountaining into the lunar sky.



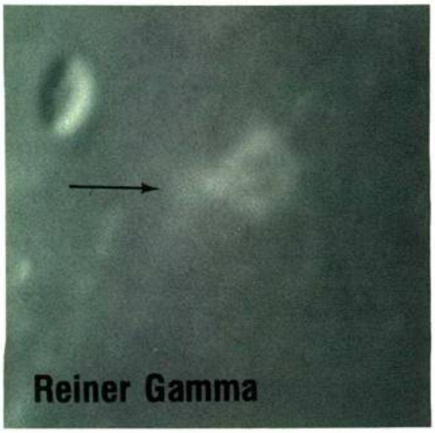
# Reiner Gamma

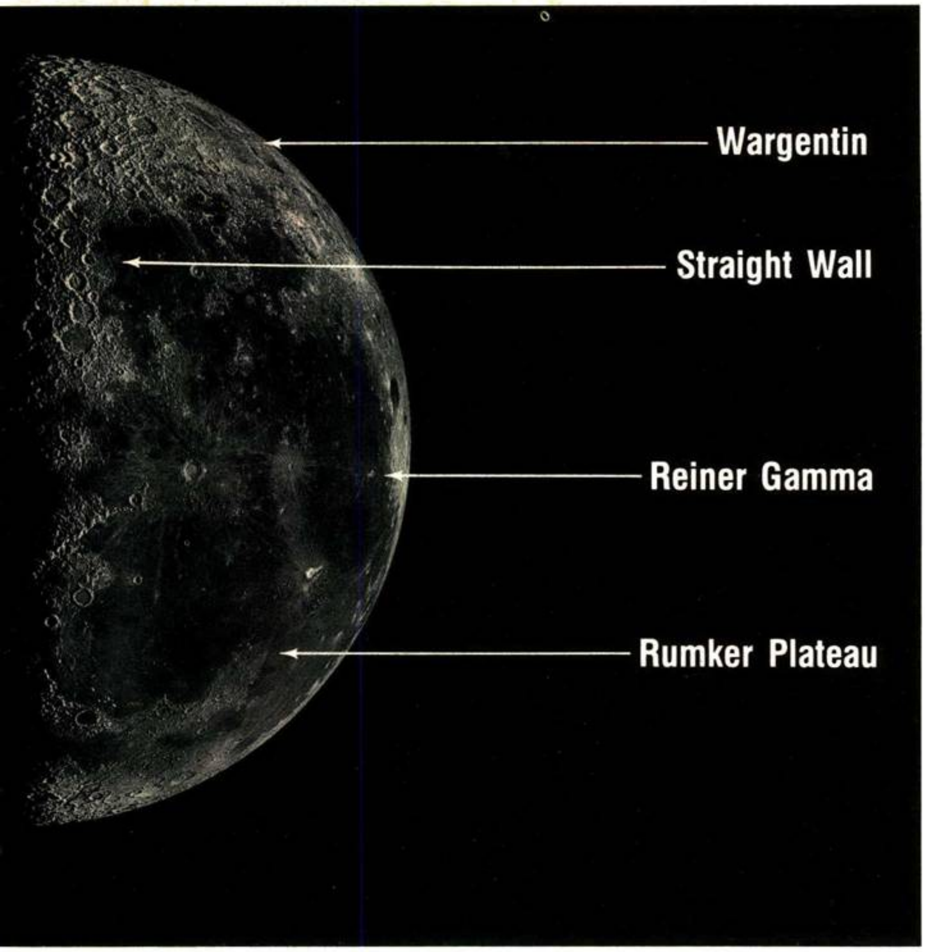
Reiner Gamma is one of those lunar features you can't quite believe you're seeing. A swirl of bright material that lies in western Oceanus Procellarum near the lunar equator, it appears to be a splash of *something* with absolutely no vertical relief. Reiner Gamma is probably made of the same kind of material as the bright rays that crisscross the Moon from a few craters. Also like the ray systems, Reiner Gamma brightens significantly as the Sun rises higher, so it always looks best at high Sun angles.

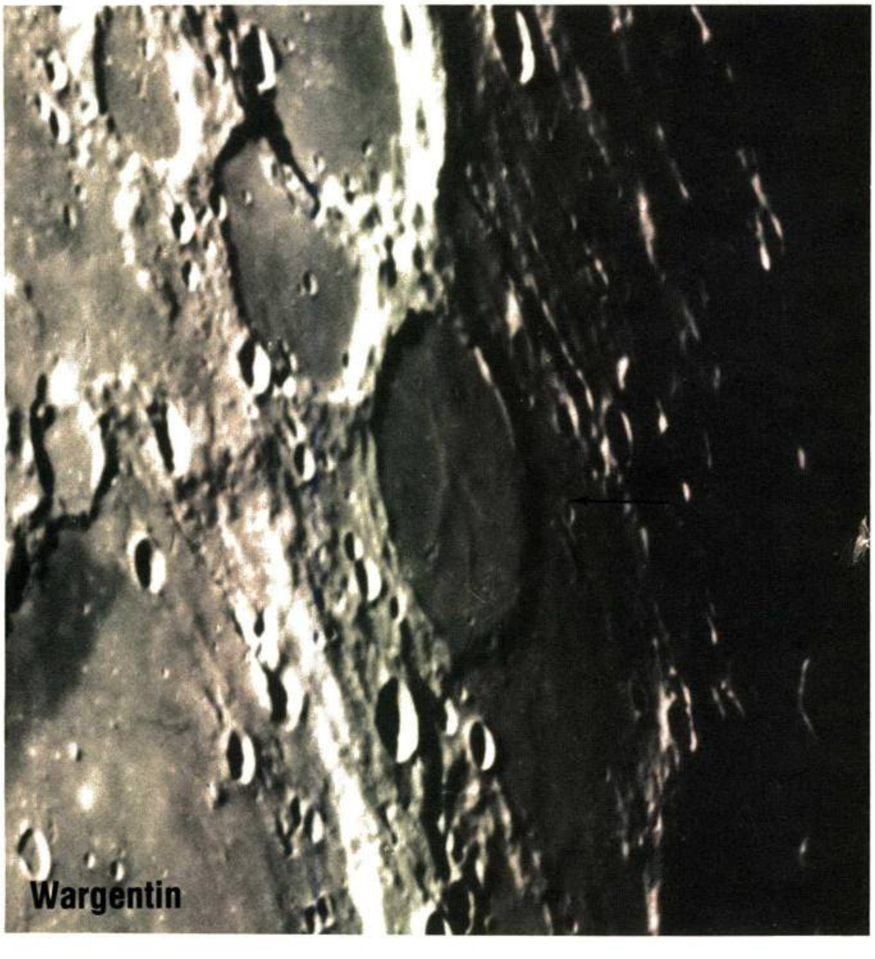
Yet lunar rays, which are pulverized rock ejected from craters during impact, usually run straight and long. Moreover, you can trace them back to a source crater. But if Reiner Gamma is a crater ray, it's the strangest one on the Moon.

Reiner Gamma remained a mystery until photographs from spacecraft revealed a second area of swirl deposits in Mare Marginis on the Moon's eastern limb. The source of this second swirl perplexed selenologists until they noted that it lay almost exactly on the opposite side of the lunar globe from Mare Orientale.

Crazy as it sounds, the Mare Marginis formation was probably created when some of the ejecta from the huge impact that formed Mare Orientale traveled completely around the globe on low orbital paths. Arriving at the lunar antipodes from all directions at once, it collided and some of it was deposited on the ground. Is this how Reiner Gamma formed? To this day lunar geologists aren't sure — for one thing, Reiner Gamma has no clearly identifiable source — and it still eludes easy characterization.







# 'Brimful' Wargentin

Moving farther south, we reach the last of our lunar oddities. The crater Wargentin is sited in a jumbled highland area near the southwest limb of the Moon. It would be difficult to locate were it not nestled just behind the juncture of two large craters, Schickard and Phocylides. At local sunrise just before Full Moon, these two craters dominate the area.

Wargentin, although 50 miles in diameter, appears smaller because of its proximity to the lunar limb, where it appears strongly foreshortened. Wargentin is the largest of a very rare class of craters that are filled to the brim with lava and look like a mesa. As the terminator crawls across its raised floor, you can trace one main wrinkle ridge running down the center and branching like a bare tree in the northern half. Low Sun reveals additional places where lava unevenly filled the crater, leaving small bumps and depressions that will remind you of chocolate pudding.

Years ago Wargentin was thought to offer a good case for a volcanic origin of lunar craters. Today we know that like the vast majority of lunar craters Wargentin was formed by meteoritic impact. However, while some craters have been modified by volcanic activity catalysed by the force of impact, Wargentin got an exceptionally heavy dose of lava in-fill. You won't find its like anywhere else on the Moon.

The Moon is much more than an infinity of stark craters and Sun-baked lava plains. As you sweep your telescope across the face of the Moon, stay alert for the unusual features, the lunar oddities tucked away everywhere you look. It's unlikely you'll ever see anything change, but it is also clear that some strange things have gone on up there in the past. Every telescope owner knows about craters. But how many go beyond the obvious and discover the Moon's *really* interesting sights? ☐

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*Michael T. Kitt is a member of the Association of Lunar and Planetary Observers, the American Lunar Society, and a contributing editor to* The Observer's Guide. *His most recent article, "One Day at Copernicus Crater," appeared in the September 1988 issue.*

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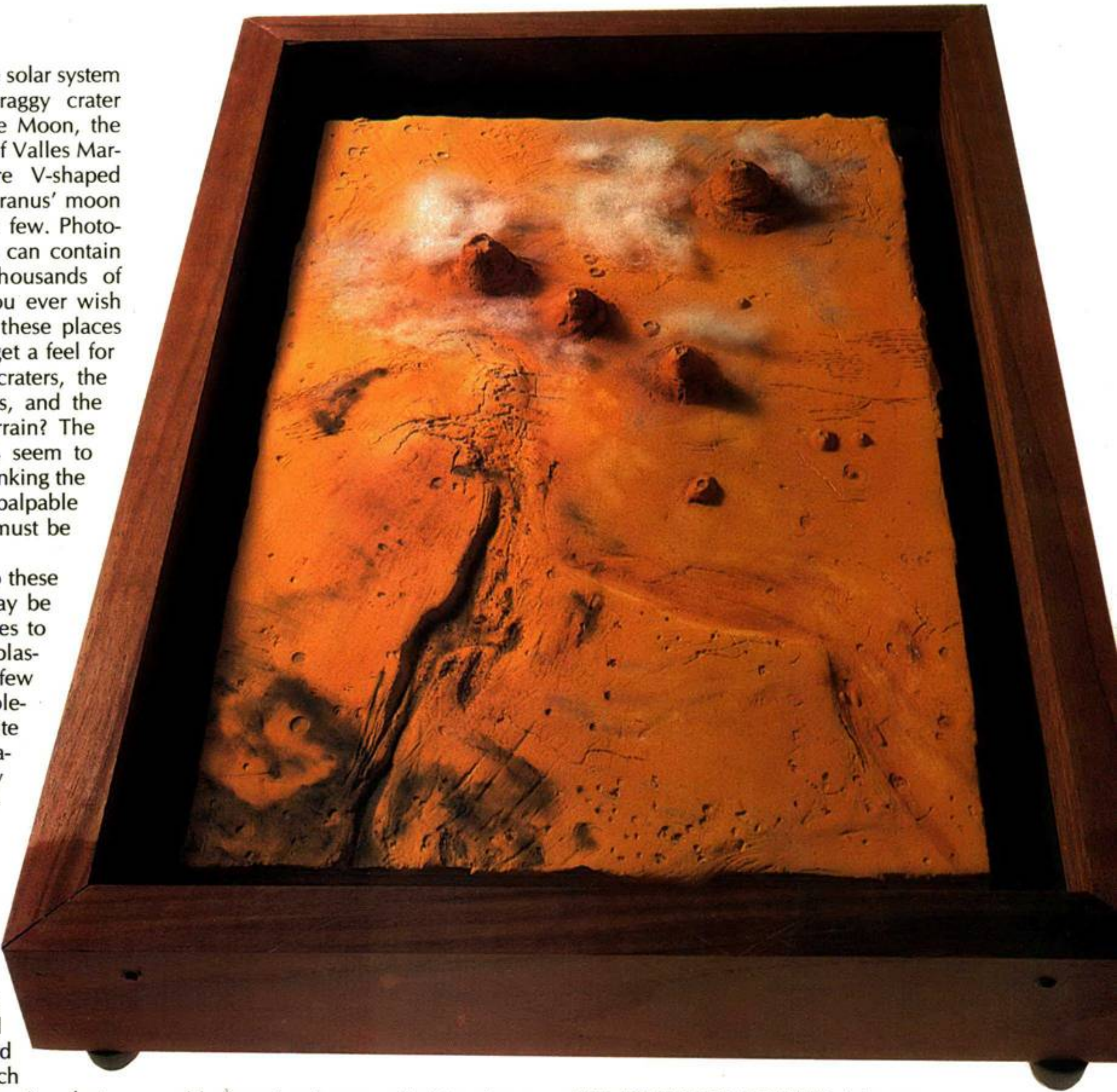
# Your Own Piece of the Solar System

### You'll get a detailed, close-up perspective of other worlds when you model your favorite planetary features.

by Ferdinand Miller, Jr.



**THE VOLCANOES OF MARS** take on a new realism when you model these features using matte board and plaster.

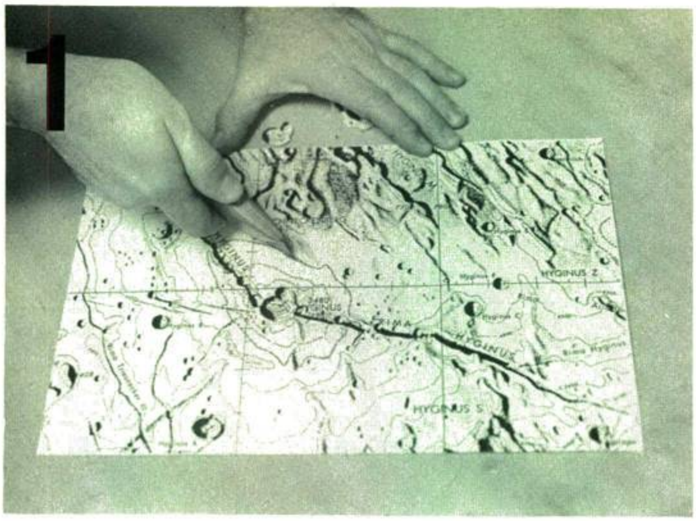
Some features in the solar system stand out: the craggy crater Copernicus on the Moon, the grand Martian canyons of Valles Marineris, and the bizarre V-shaped "chevron" feature on Uranus' moon Miranda, just to name a few. Photographs of these features can contain great detail covering thousands of square miles. But do you ever wish you could actually see these places with your own eyes to get a feel for the true depth of the craters, the height of the mountains, and the general relief of the terrain? The two-dimensional photos seem to constrain the image, shrinking the landscape to a flat, impalpable representation of what must be a visually thrilling site.

Though we can't go to these places ourselves, we may be able to bring these places to us. Using matte board, plaster, a little paint, and a few tools, you can make tabletop models of your favorite lunar and planetary features that are not only fun to do but also represent a three-dimensional piece of the solar system.

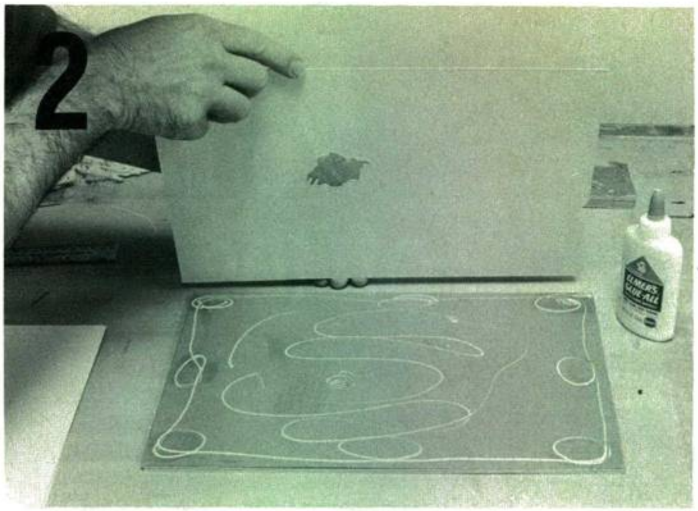
The supplies you'll need depend on the size and detail of your model. A basic list includes the following: a piece of ¾-inch plywood for your base, matte board for features, a sealer (such as Krylon Crystal Clear), plaster powder, a mixing container, and a foam brush to apply the plaster. To sculpt the fine details into the model and give it realistic surface color, you will need a regular artist's brush, an atomizer, a Dremel Moto-Tool, dry paints, and, if you can obtain one, an airbrush.

Many of these materials are available from hardware or hobby shops. Or if you happen to know someone who builds model railroads, chances are he or she will have all the tools you will need.

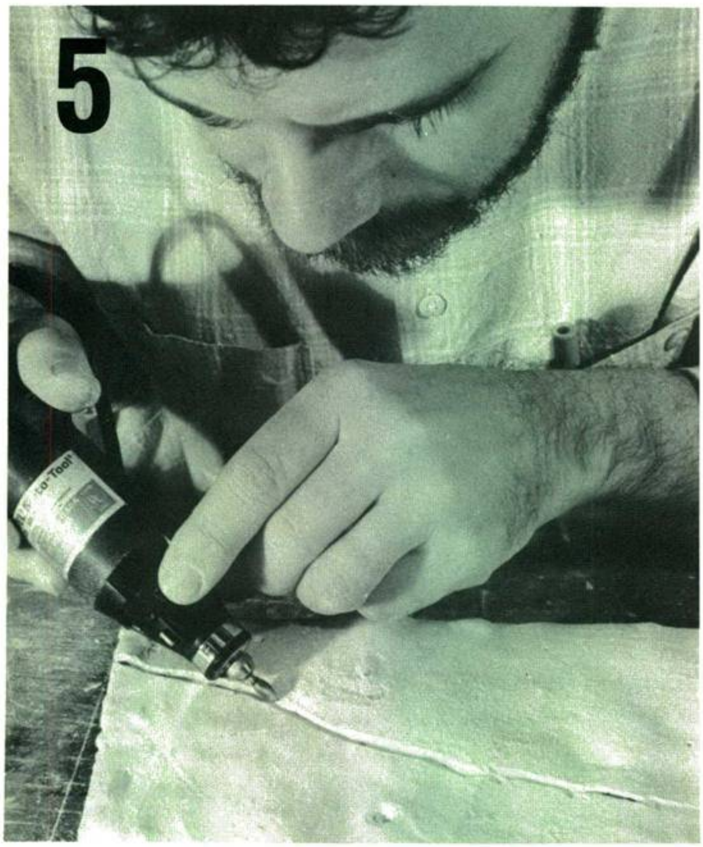
The first decision you have to make is what to model. Of course, you can choose to model anything from a single crater to the surface of an entire planet, but bear in mind that a balance must be struck between size and detail. If your ambitions tend toward building a grand-sized model of a small area, a lot of detail will have to be included to make the model accu-



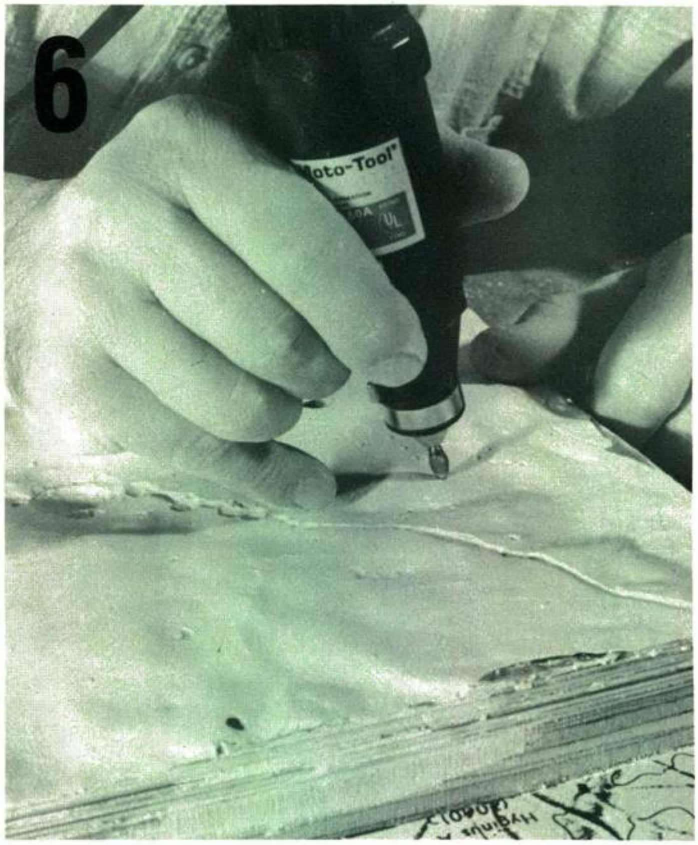
After gluing the maps to the matte board, cut out the different contours with a utility knife. You will end up with some odd-shaped pieces.



Starting with the lowest elevation, glue each cutout contour on top of the others. Make sure you position each contour relative to the contour below it.



After the model dries, etch out canyons and valleys with a Dremel tool. Additional relief material, such as low hills, can be added with extra plaster.



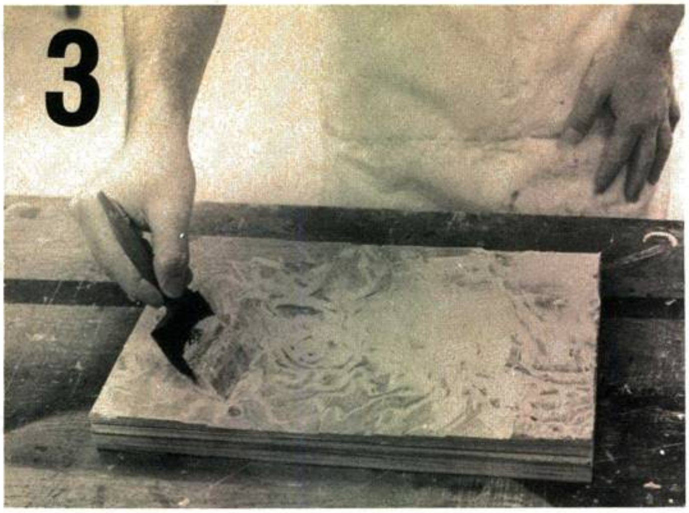
Craters are made with a router bit in the Dremel tool. Lightly touch the bit to the surface for a circular cut or draw the bit along the surface for an oblong crater.

rate on a large scale. Conversely, you can get by with less detail if you make your model smaller, except that you *don't want* to make it so small it has no visible detail.

Closely related to this decision is the amount of relief you want in your model. The greater the difference between the highs and lows, the greater the drama. Generally your decision depends on what material you can get your hands on to construct the model's relief features. Poster board or matte board are easy to get from art and craft stores, and thin plywood can be obtained from a lumber outlet.

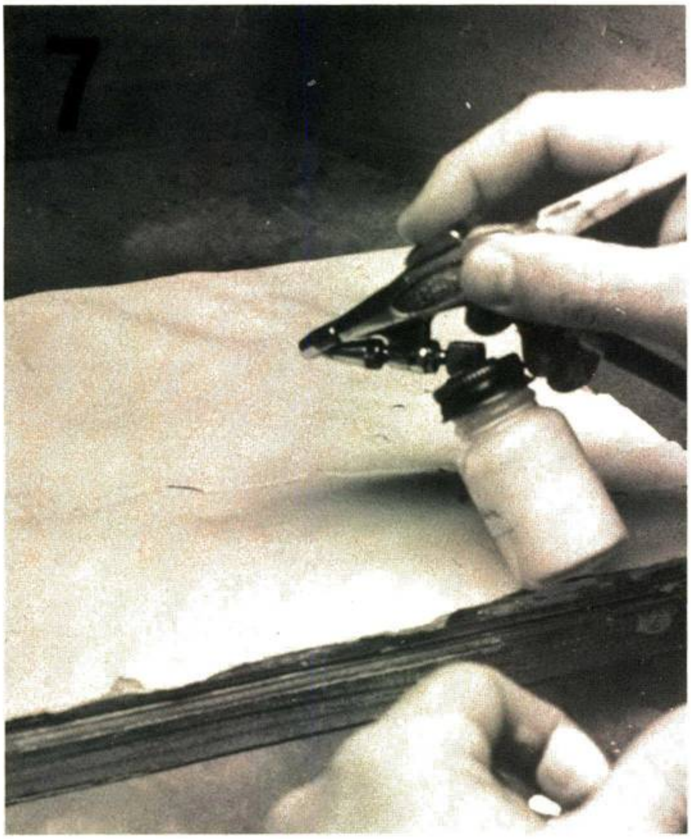
For your first model, select something easy but not without some challenge. I selected a region on Mars that includes the Tharsis Bulge and parts of Valles Marineris and Lunae Planum. This region has some overall relief, though not too much, and includes four prominent volcanoes, which add drama to the model.

*You need a good topographic map* of the area that gives contour elevations and photographic detail. For Mars I selected a book entitled *The*

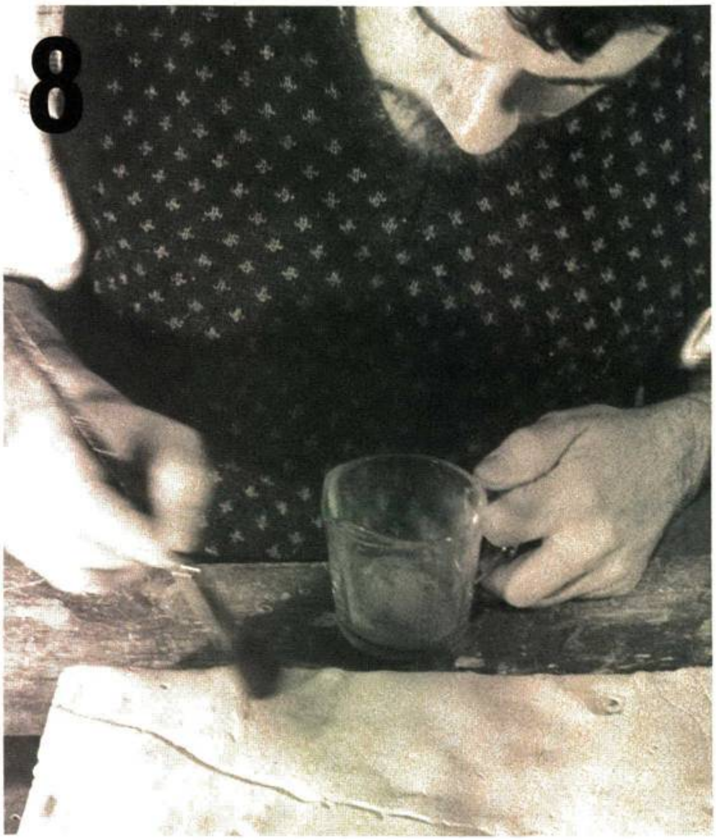


Spread on the plaster quickly, stroking uphill against the contours. Take care not to make hollows in the plaster and that the low areas don't get overfilled and lost.

Gently smooth the surface of the model with wet hands. This will give your model an overall consistency and help even out the distribution of plaster.



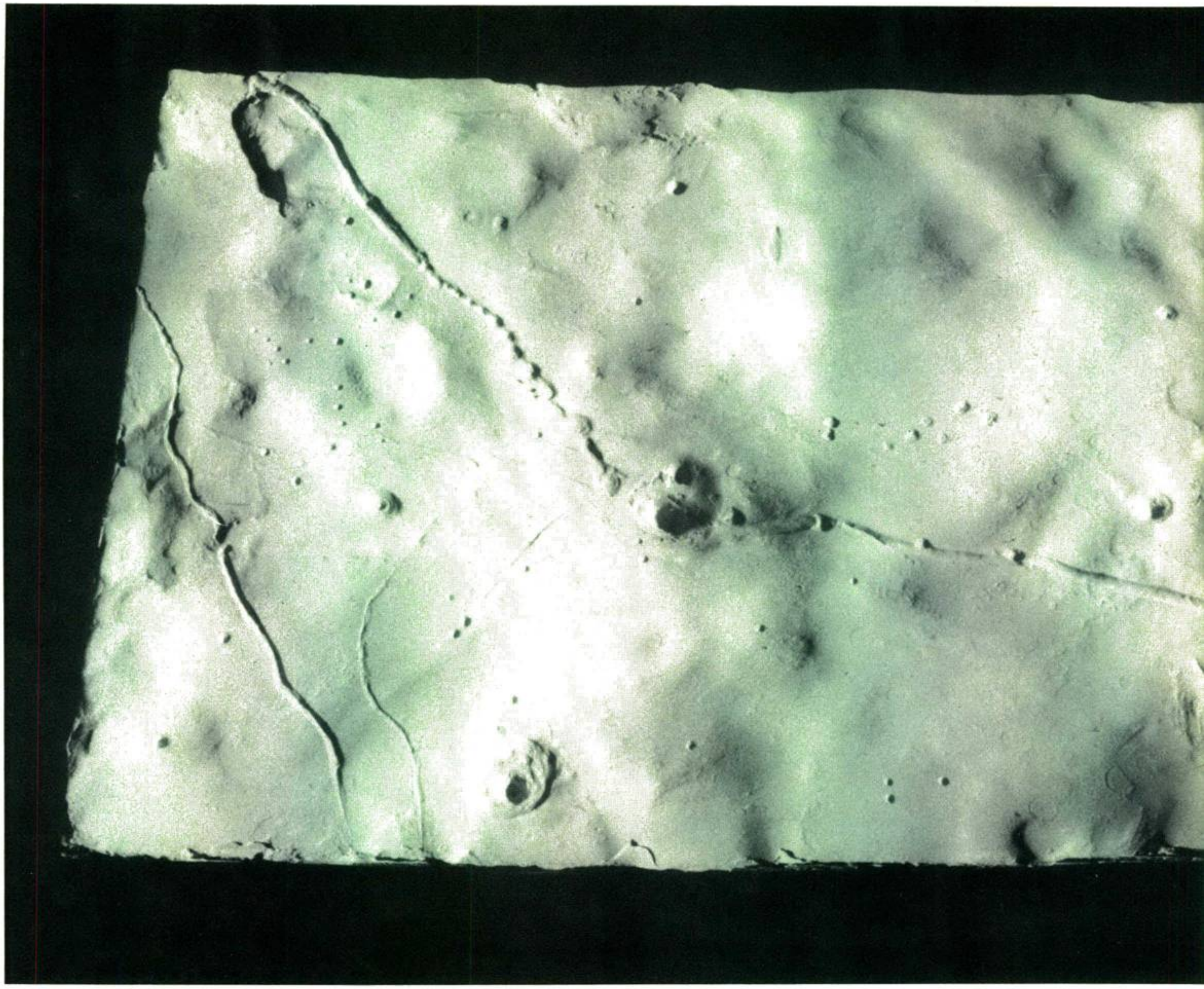
After spraying the surface with flat white model paint, spray on a base coat using the lightest shade of your final color. If possible, use an airbrush for a more even application.



Use dry pastel paint that is close to your base color to highlight your model. Makeup or soft camel's hair brushes work well in applying the powdery paints.

*Surface of Mars* by Michael Carr (Yale University Press, 1981), which had all the information I needed. For topographic maps of the Moon, Mercury, Venus, Mars, and the Galilean satellites, write the U.S. Geological Survey Distribution Center, USGS Map Distribution, Federal Center, Building 41, Box 252186, Denver, CO 80225. For information on what maps are available you can call the center at (303) 236-7477. Another good source for topographic maps is Willmann-Bell, Inc., P.O. Box 35025, Richmond, VA 23235.

The first step is enlarging a copy of the map to the size you want your finished model to be with a photocopier that can enlarge copies (you may have to enlarge the enlargement to get the size you want). Then make as many copies as there are different contour lines or lines of equal elevation. For each contour elevation, glue one copy of the enlarged map on the material of your choice. Trim the maps to ensure that each is the same size. Also, make sure the poster board is the same size as the maps and square with each other. This helps keep the contour fea-



**A THREE-DIMENSIONAL MODEL** of the Moon's Hyginus crater and rille shows that the crater lies in a depression and that the rille is surrounded by rolling hills.

tures aligned when you stack the different pieces.

Next, select one of the maps and carefully cut out a contour feature — usually the lowest elevation. Do not cut out more than one contour feature per map unless those contours are at the same elevation. For example, if you have a 5700-meter feature on one side of the map and a 5700-meter feature on the other side, cut both out of the same map.

The next task is to sandwich these different contour features one on top of the other to form the terrain's relief. Starting with the lowest elevation, glue each cutout sheet down on top of the previous one. Be careful to stack each contour shape in relation to the contour shape beneath it (again, it helps if the maps are square). It is sort of like fitting a jigsaw puzzle together from the bottom up.

When you finally get a stack of glued-down sheets, sand the sharp edges with a small piece of sandpaper. In the canyons I found the Dremel motor tool with a pointer cutter useful, but be sure not to sand too much or you will reshape the landform. Spray the whole layout with a sealer of some sort. I used a light spray of Krylon Crystal Clear. This will seal the surface to prevent swelling or separating after you add the plaster.

If your model has mountains, build them separately and glue the mountain stacks on to the model where they belong. A Dremel tool is especially helpful for roughing out the shape of the mountains unless you are good at carving. Remember, you're not trying to form a finished shape yet, only to remove the sharp corners and burrs.

The next step is to put down the base coat of plaster that you will carve away and add to. I used Hydrocal, which is a very hard and fast-drying plaster. (This kind of sculpting plaster also goes under the name of Ultracal.) Regular patching plaster is too soft. Hydrocal comes in 50-pound bags and can be purchased at most hobby shops for around $18. You can also use a mixture of papier mache and plaster called Sculptamold, which comes in 3-pound bags for about $4.60. Sculptamold dries much slower than Hydrocal but has a slightly rougher finish. However, this can be smoothed out fairly well with your fingers as it dries.

Add the plaster to the water a little at a time, mixing continuously until it has the consistency of thin pancake batter. Wet the surface of the model with the atomizer and then brush on the plaster with the foam brush, stroking uphill against the contour pieces.

Fill in the valleys, cover the mountains, and then use the small artist's brush to clean out the valleys and even the coat on the mountains. Fill the area between contour elevations so you don't get a series of terraces. If you're using Hydrocal, act quickly: you only have five to ten minutes before the plaster sets. Cover it all like frosting on a cake, but make sure the low areas do not get filled in and lost. Keep dipping your brushes in water so they don't get gunked up.

When you are satisfied you've adequately covered the model, let it dry slowly. Again, if you're using Hydrocal, spray the whole model dripping wet with an atomizer and keep spraying it for an hour until it looks flat and dry. The trick is to not let it dry too fast or stress cracks will appear, and I promise you they will not be where they are supposed to be.

If your contour pieces are more than 1/16-inch thick, you can dip small pieces of hand towel in the plaster and lay them over the surface, overlapping the pieces and smoothing the joints as you go with plaster-dipped fingers. This bridges the layers and saves considerably in plaster. Just make sure you push the plaster-soaked pieces well down into the valleys.

Detailing involves filling, sanding, and carving: filling to add plaster where land mass is lacking; sanding to remove brush marks and extra globs; and carving to add craters, dry river beds, volcano details, and water-erosion marks. For fine details I used a Dremel tool exclusively and was able to finish up in a couple of hours.

Wet any area of the model that you need to add plaster to, because a dry base causes the new wet plaster to dry too quickly. If the new plaster you add is Hydrocal, wet it for one-half hour by misting with plain water.

Obtain an assortment of small Dremel routing bits, the type with the flat bases that taper upward. Get all sizes from the smallest to the largest. With these you can fashion all sizes and shapes of craters.

Round craters are made by simply touching the router to the surface, while oblong ones are made by drawing the router along the surface. Terraced craters and calderas can be simulated in two ways. The first is by just lightly touching the surface with the largest bit and then with a succession of smaller bits in the center of each preceding cut. Another way is to use the smallest router bit and swirl it around in larger and larger circles until the overall crater diameter is formed.

Tributary canyons, land slips, and stress cracks in my Mars model were all cut with repeated passes by the sharp bit of the smallest flat-based router. A pointed router can be used for even thinner cracks. The small volcanoes were made out of a dollop of plaster and then dry-carved with the Dremel tool.

If you get tired of craters, go on to canyon work or cracks, faults, or volcanoes. A little here and a little there. While working blow away or vacuum up the powder that forms. Don't worry if you accidentally nip into the cardboard or wood base. The painting step will hide this.

When the model is carved to the desired level of detailing, spray the whole model with flat, white model paint. To keep the coat of paint really thin and even, use an airbrush instead of spray paint. Spray can nozzles cans lay out too much paint that can fill in fine details.

After the undercoat dries, spray the model with an overall base color. For my Mars model, Floquil Harvest Yellow seemed best. If you're doing the Moon, some shade of gray would be suitable. A word of caution, however: For this base color use a lighter shade of your final color. It is easier to darken areas later than to lighten them.

When the base color is dry, use powdered pastels to add color to your model. I used stick pastels and turned what I needed into powder by rubbing the sticks on sandpaper (you don't need much). Keep the colors in separate containers and mix what colors you need. Brushes used for applying makeup work well. Mix a batch that is close to your base color and add whatever color you are applying to average out the color range so it doesn't get too gaudy. Build up shades with successive applications of color.

If the final effort looks gaudy, don't worry. A final overspray of paint, just a dusting of the base color, will blend things together. You can put in highlights just by using a rubber eraser to expose some of the white Hydrocal. If your model requires misty clouds, try wispy pieces of cotton placed over shadowed areas of the model.

One important point is to paint your model in the same light in which the model will be displayed. The same colors that look one way under fluorescent light will look vastly different under tungsten lighting or even under different tones of the same type of light such as warm and cool, yellow, or white. If you have complete freedom over the display lighting, you can customize to bring out the best colors.

If you want to emphasize the carved details, keep the display light at a low angle to the surface, which produces a sunrise effect. I used a book light with the shade removed. If you don't want the details to show as well as the coloration, then keep the light overhead. Avoid using two bulbs close to the model because double shadows will result.

To protect your masterpiece, you can build a wooden case and cover it with glass or thermoplastic. Attach a sign and maybe even a short description to the display case so people unfamiliar with otherworldly features of the solar system know what the model represents. With this model completed, perhaps you will feel inclined to try something more ambitious next time. How about a live volcano on Io? □

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*Ferdinand Miller, Jr., is an amateur astronomer who lives in New Canaan, Connecticut. He made the Mars model for a local museum.*

THE BACKYARD ASTRONOMER

# Galaxy Hunting around the Big Dipper

Explore the spiral arms and dust lanes
of bright springtime galaxies around the Big Dipper.

by Alan Goldstein

Galaxies are the most varied, beautiful objects visible in backyard telescopes. They range from naked-eye visibility to dim smudges barely visible in big telescopes, from graceful spirals to featureless blurs. Besides stars, galaxies are the most abundant class of objects in the sky — roughly 10,000 are visible in amateur telescopes. Springtime offers an especially good opportunity for galaxy hunting, because the evening sky turns away from the cluttered winter Milky Way and lets us see far out into the depths of the universe.

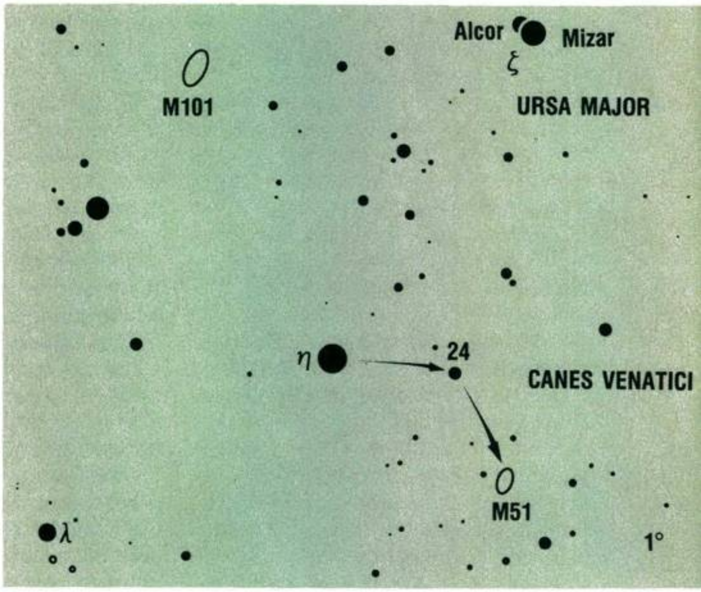
The finest galaxy by far in the spring sky is **M51** (NGC 5194), the Whirlpool Galaxy in Canes Venatici. Called the Whirlpool because of its distinctive spiral pattern, M51 glows at magnitude 8.4 and spans 11′ by 8′, which makes it one of the brightest and largest spiral galaxies in the sky. Because M51 is almost exactly face-on to our line of sight, its spiral pattern and other details are easily visible.

As if that weren't enough, M51 is the brightest component of an interacting pair. **NGC 5195**, a small peculiar galaxy, is interacting with the outer part of M51 and distorting both galaxies in the process. Two- to 6-inch telescopes show the galaxies as a double patch of misty light. Eight-inch or larger telescopes show the faint bridge of light that connects the two galaxies.

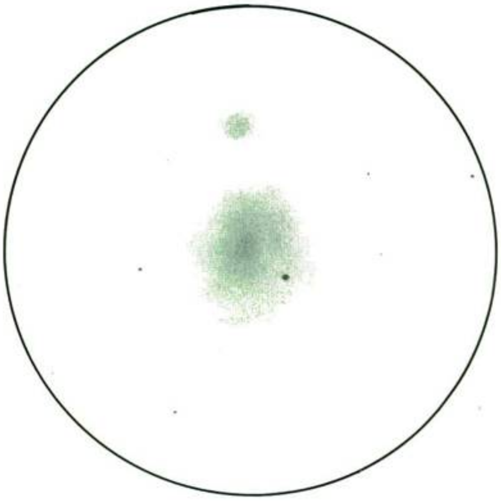
To find M51, aim your telescope at Alkaid (Eta [η] Ursae Majoris), the "end" star in the handle of the Big Dipper. Make sure you're using a low-power eyepiece so the field of view is as large as possible; you can switch to higher powers once you've found M51. Carefully aim the telescope 2° east to the 5th-magnitude star 24 Canum Venaticorum. Now move the scope 1.5° south to a group of three 8th-magnitude stars that form a near right triangle. M51, which appears in finder scopes as a small circular haze, is located just east of the southernmost star in this triangle.

Once you've found M51, what you'll see depends on the telescope you're using. A 60mm refractor shows M51 as a tiny oval smear of gray light set against a sparse field of a dozen faint stars. With a 4-inch telescope, however, you'll resolve M51 and NGC 5195 and see a double glow. At moderate or high powers a 4-inch scope shows a slight central brightening in M51.

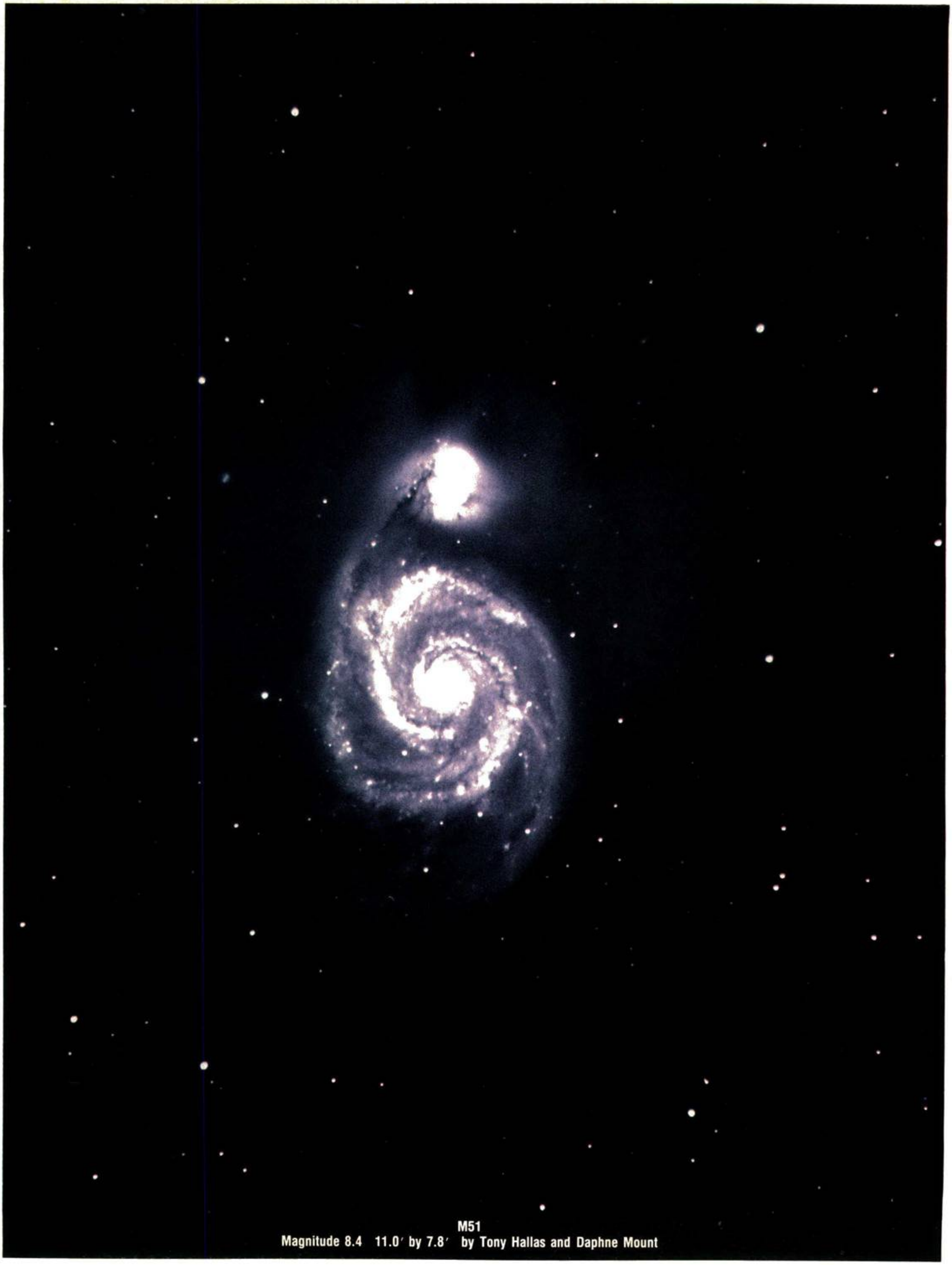
A 6-inch scope at 100x shows M51 as a large, oval patch of light with a smaller, circular glow, NGC 5195, just northwest of the large glow. In addition to the soft glow of the galaxies, the field of view contains one 8th-magnitude star 35′ east-northeast of M51. This star



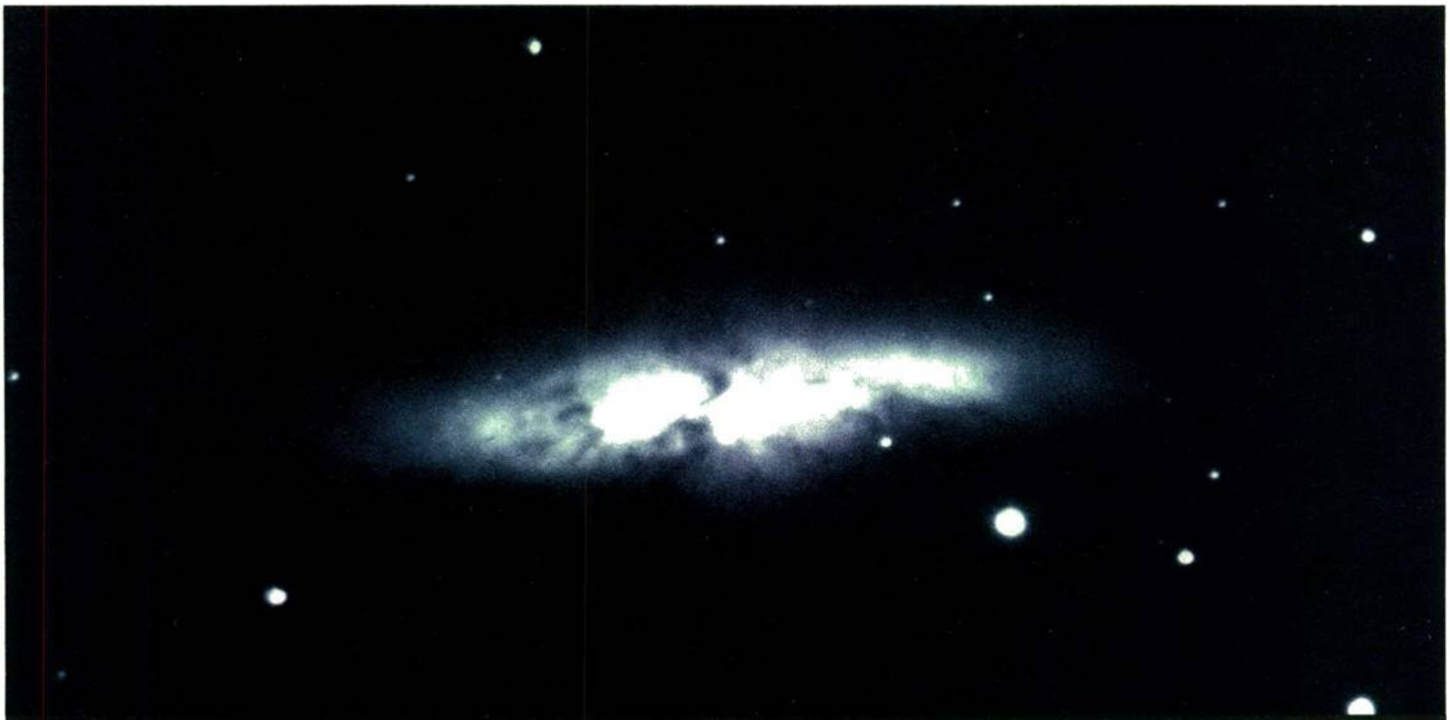
**A 6-INCH SCOPE** is required to see spiral structure in M51. On very dark nights 8-inch telescopes reveal a clear spiral pattern and a "bridge" of light linking M51 with NGC 5195.



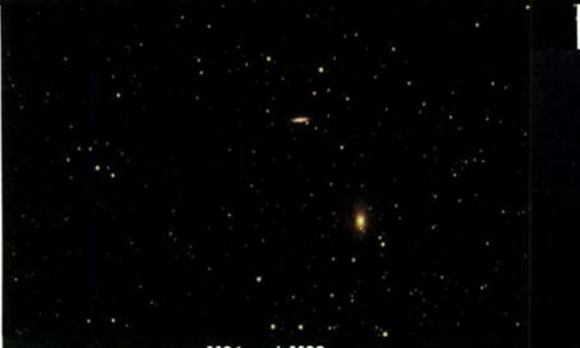
M51
8-inch f/10 SCT 100x by David J. Eicher



M51
Magnitude 8.4  11.0′ by 7.8′  by Tony Hallas and Daphne Mount

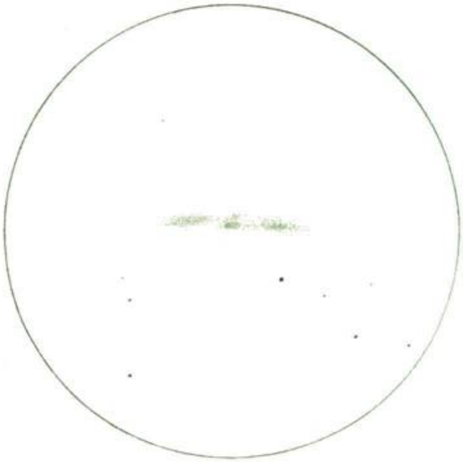


M82
Magnitude 8.4 11.2′ by 4.6′ by Kim Zussman

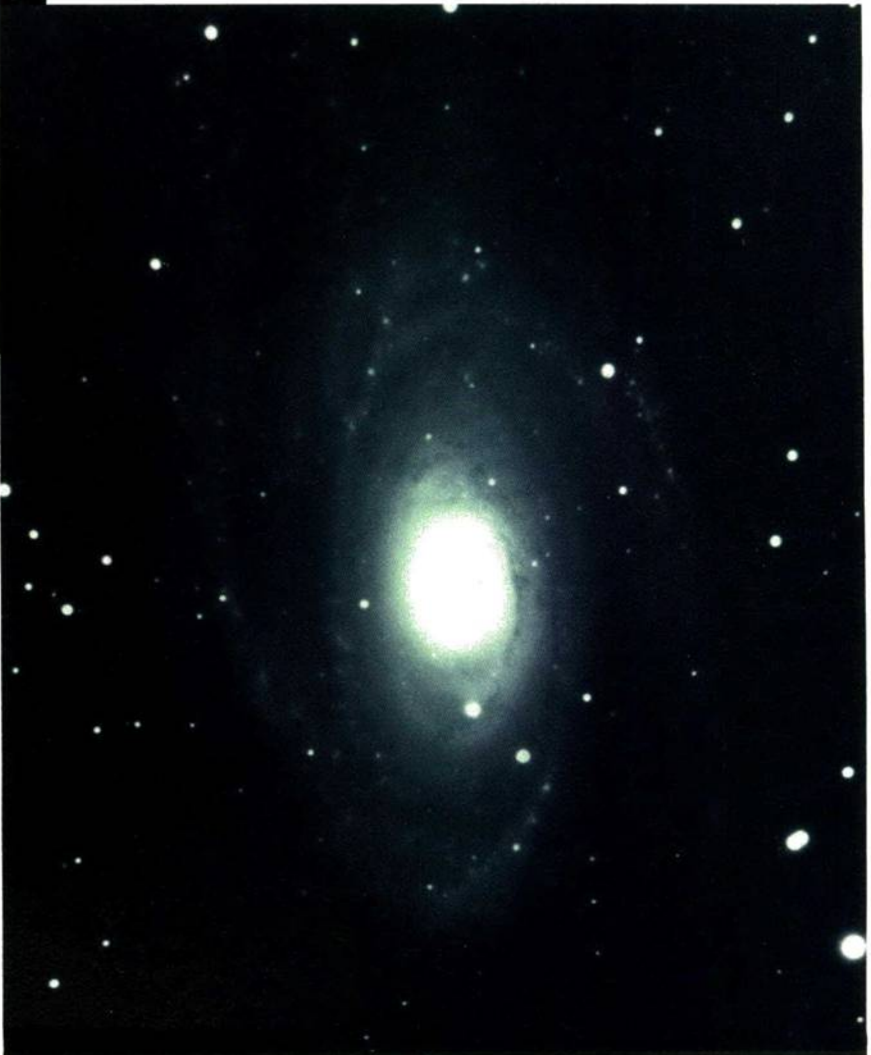


M81 and M82
by Mace Hooley

**THE BRIGHTEST** galaxy pair in the sky is M81 and M82 in northern Ursa Major. Small telescopes show a double patch of light: M81 is oval-shaped and its neighbor distinctly flattened.



M82
8-inch f/10 SCT 100x by David J. Eicher



M81
Magnitude 7.0 25.7′ by 14.1′ by Kim Zussman

is the southernmost of the three that form the right triangle. Midway between the galaxy and star is a small, distinctive triangle of 11th- and 12th-magnitude stars. Apart from this, the field is rather uniformly scattered with two dozen faint, white stars.

A good 6-inch or 8-inch telescope provides sufficient light-gathering power to show significant detail in the Whirlpool Galaxy. With high magnification, the first thing you'll notice is that the disk of M51 is not uniformly illuminated. The galaxy's core is significantly brighter than the glow that surrounds it. The surrounding glow appears mottled, or unevenly lit. On nights when the atmosphere is particularly transparent, you'll see the mottling isn't random but rather that the galaxy's disk is composed of spiral arms. This spiral pattern can be glimpsed with a 6-inch scope on the best of nights.

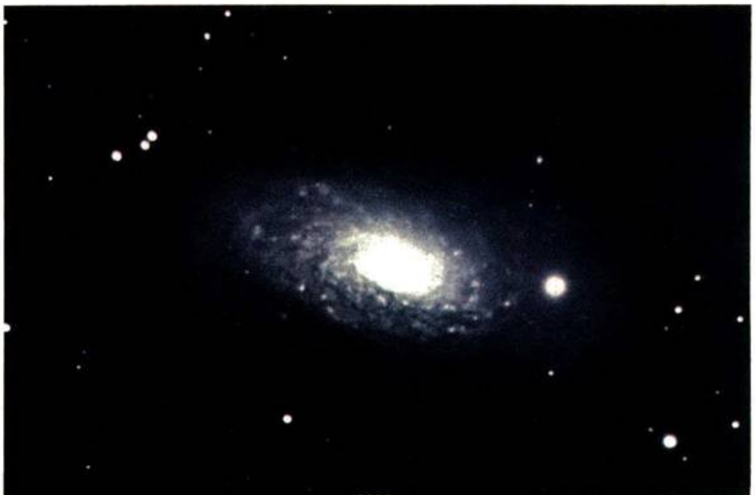
M51 in large amateur telescopes shows a wealth of detail not discernible with small scopes. A 12-inch telescope reveals a tiny, brilliant, starlike point of light in the galaxy's center. This pinpoint core lies within a 2'-diameter oval-shaped central glow. Surrounding the central glow are the galaxy's spiral arms, plainly visible on steady nights.

M51 contains two primary arms. One begins at the southern end of the central glow and winds clockwise, smoothly disappearing against the background sky. The other arm begins at the northern end of the central glow and winds clockwise, connecting to NGC 5195. The arms are clearly delineated by dark lanes; NGC 5195 also has dark patches that give it a mottled appearance in large telescopes. A solitary star dimly glowing at 12th magnitude lies 2' southwest of M51's center. This star is occasionally mistaken for a supernova in M51, but it actually lies within our Galaxy, hundreds of thousands of times closer than M51 itself.

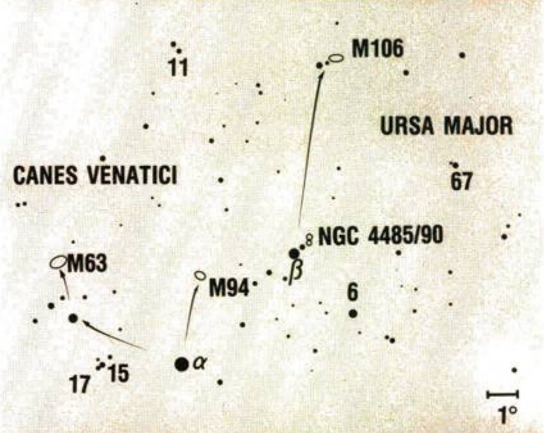
No matter what size telescope you have, two observing tricks will help you see detail in M51 and other galaxies. First, give yourself a minimum of twenty minutes in total darkness before observing so your eyes will perform at maximum sensitivity. This dilates your pupils and allows you to see faint light you would not see immediately after exposure to inside lighting. Second, use averted vision. Centering a galaxy in your field of view and glancing off to the edge of the field uses your eye's rods, the most sensitive receptors. With this technique you will often see details in a galaxy that are not visible when you look directly at the galaxy.

After M51, the finest galaxy in the spring sky is **M81** (NGC 3031) in Ursa Major. This bright spiral forms a wide pair with **M82** (NGC 3034), a peculiar galaxy oriented edge-on to our line of sight. To find the M81-M82 pair, aim your telescope at Dubhe (Alpha [α] Ursae Majoris), the end star in the bowl of the Big Dipper. Sweep 12° west and 2° north to 23 Ursae Majoris, a 4th-magnitude double star. Next, go 7° north to a 1°-long row of three stars, the brightest of which is 24 Ursae Majoris. From this point move your telescope 2° southeast to M81 and M82.

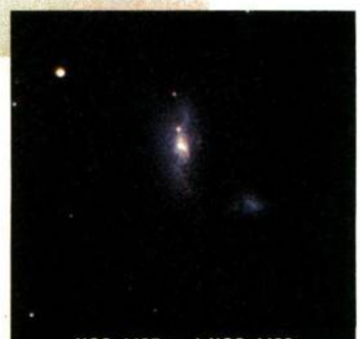
Once located, M81 and M82 are visible together in the same low-power telescopic field. Although M81 is brighter than M51, it is not nearly as detailed. A 4-inch telescope shows M81 as an oval-shaped nebulosity some 5' across and M82 as a smaller and much fainter sliver of gray light. Six-inch telescopes reveal a tiny, bright nucleus in M81 and a mottled appearance across cigar-shaped M82 (this is caused by dust lanes that cross the



M63
Magnitude 8.6 12.3′ by 7.6′ by Kim Zussman



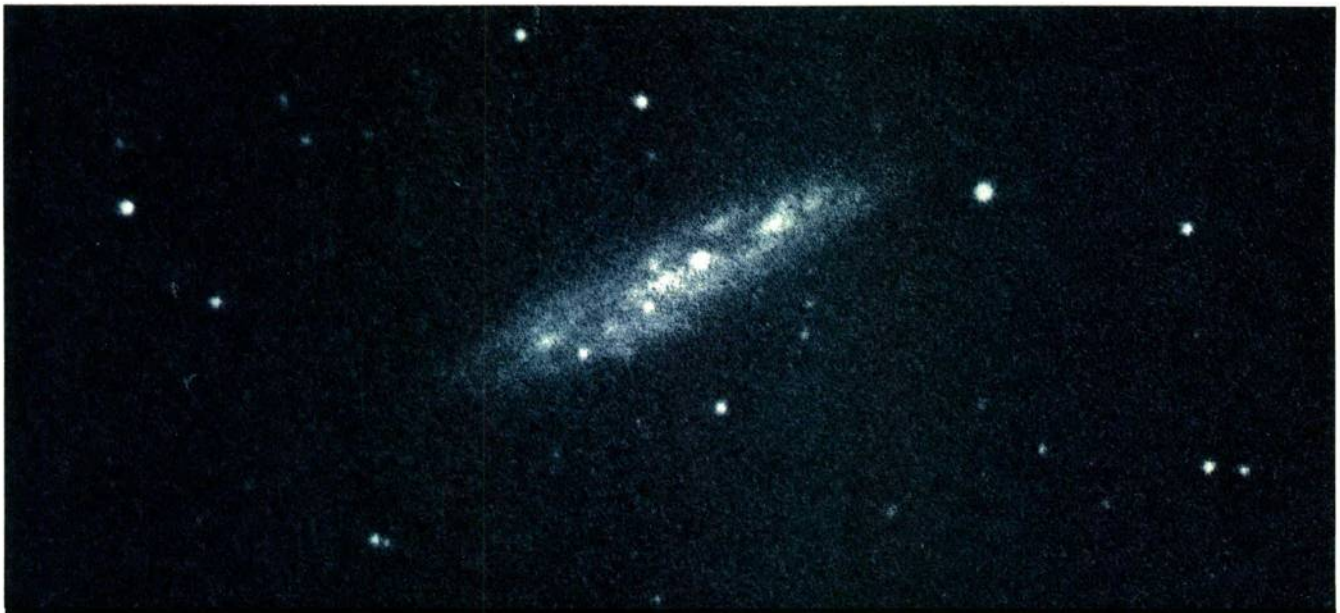
M94
Magnitude 8.2 by Jack Newton



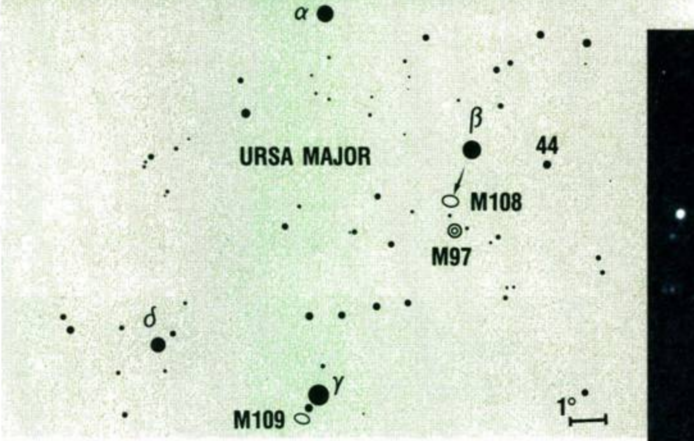
NGC 4485 and NGC 4490
Mag. 12.0 and 9.8 by Jack Newton

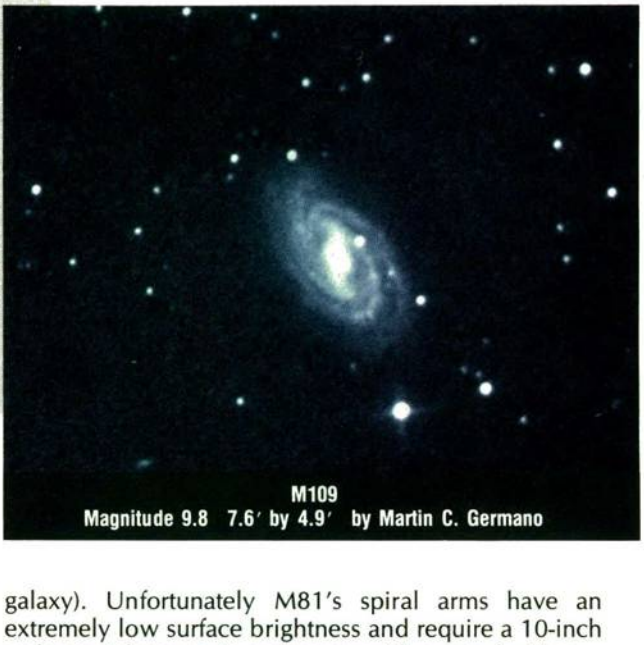
M106
Magnitude 8.3 18.2′ by 7.9′ by Jack Marling

**FIVE BRIGHT GALAXIES NESTLE** in central Canes Venatici. M63 features spiral arms visible in large backyard telescopes. M94 has a tiny, bright nucleus. NGC 4485 and NGC 4490 form an interacting pair. M106 has arms visible in a 10-inch scope.



M108
Magnitude 10.1 8.3′ by 2.5′ by Martin C. Germano





M109
Magnitude 9.8 7.6′ by 4.9′ by Martin C. Germano

**SWIMMING IN THE BIG DIPPER'S BOWL** are spiral galaxies M108 and M109. Small telescopes show M108 as a silver streak. M109 appears like an oval nebulosity with a bright center.

## Bright Springtime Galaxies

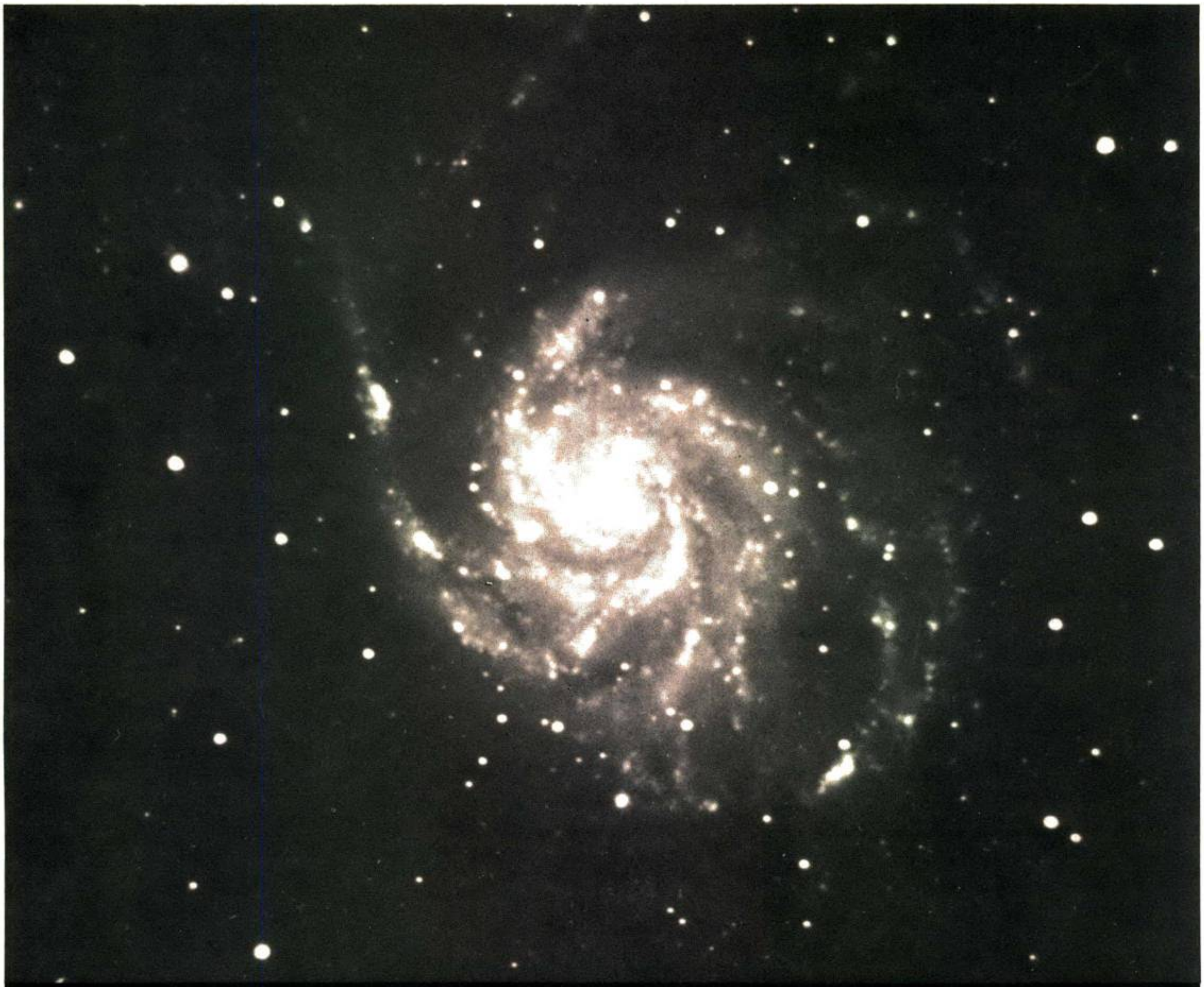
| Object | R.A. (2000.0) Dec. | Mag. | Size | *Tirion* | *Uranometria* |
|---|---|---|---|---|---|
| M81 | 9h55.6m +69°04′ | 7.0 | 25.7′ by 14.1′ | 1, 2 | I: 23 |
| M82 | 9h55.8m +69°41′ | 8.4 | 11.2′ by 4.6′ | 1, 2 | I: 23 |
| M108 | 11h11.5m +55°40′ | 10.1 | 8.3′ by 2.5′ | 2, 6 | I: 46 |
| M109 | 11h57.6m +53°23′ | 9.8 | 7.6′ by 4.9′ | 2, 6 | I: 47 |
| M106 | 12h19.0m +47°18′ | 8.3 | 18.2′ by 7.9′ | 2, 6 | I: 74 |
| NGC 4485 | 12h30.5m +41°42′ | 12.0 | 2.4′ by 1.7′ | 7 | I: 75 |
| NGC 4490 | 12h30.6m +41°38′ | 9.8 | 5.9′ by 3.1′ | 7 | I: 75 |
| M94 | 12h50.9m +41°07′ | 8.2 | 11.0′ by 9.1′ | 7 | I: 75 |
| M63 | 13h15.8m +42°02′ | 8.6 | 12.3′ by 7.6′ | 7 | I: 76 |
| M51 | 13h29.9m +47°12′ | 8.4 | 11.0′ by 7.8′ | 7 | I: 76 |
| NGC 5195 | 13h30.0m +47°16′ | 9.6 | 5.4′ by 4.3′ | 7 | I: 76 |
| M101 | 14h03.2m +54°21′ | 7.7 | 26.9′ by 26.3′ | 2, 7 | I: 49 |
| M102 | 15h06.5m +55°46′ | 10.0 | 5.2′ by 2.3′ | 2 | I: 50 |
| NGC 5907 | 15h15.9m +56°19′ | 10.4 | 12.3′ by 1.8′ | 2 | I: 50 |

**Object:** Designation in Messier or NGC catalog. **R.A. and Dec.:** Right ascension and declination in equinox 2000.0. **Magnitude:** V magnitude of galaxy. **Size:** Diameter in arcminutes. ***Tirion:*** Chart on which object appears in *Sky Atlas 2000.0* by Wil Tirion. ***Uranometria:*** Chart on which object appears in *Uranometria 2000.0* by Wil Tirion, Barry Rappaport, and George Lovi.

galaxy). Unfortunately M81's spiral arms have an extremely low surface brightness and require a 10-inch or larger telescope to spot even with averted vision.

Two bright galaxies lie near the bowl of the Big Dipper. **M108** (NGC 3556) lies 2° southeast of Merak (Beta [β] Ursae Majoris), glows at 10th magnitude, and is an edge-on spiral galaxy. Visible in small scopes as a thin object resembling M82, M108 is a treat in large backyard telescopes. As with M82, we see a great deal of dark, obscuring clouds in M108 because of the galaxy's edge-on orientation. A 16-inch telescope shows small dark patches in the gray-green light of this galaxy. What appears to be a pinpoint nucleus in M108 is actually a dim foreground star.

**M109** (NGC 3992) is a magnificent barred spiral galaxy glowing at 10th magnitude and lying within the same low-power field as Phecda (Gamma [γ] Ursae Majoris). Although this galaxy's spiral structure isn't as apparent as M51's, a large backyard scope will clearly reveal it on an especially dark night. M109 is not quite face-on, and its arms have a relatively low surface brightness. Small scopes show an elongated bright center in this galaxy surrounded by a dim fuzz. A 12-inch

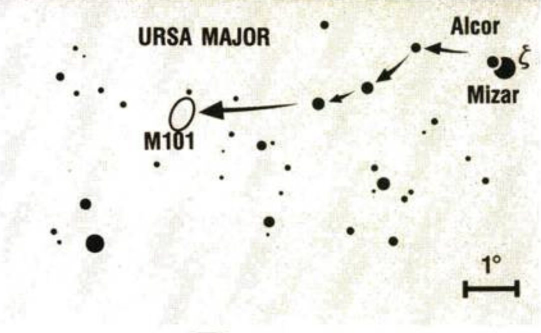


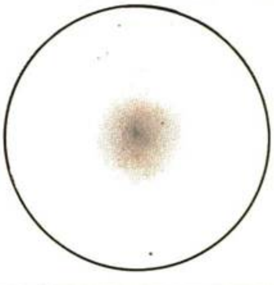
M101
Magnitude 7.7 26.9′ by 26.3′ by Paul Roques

scope at moderate power reveals the galaxy's bar and its faint spiral arms.

A group of contrasting galaxies lies south of the Big Dipper. **M106** (NGC 4258) can be found next to a 6th-magnitude star some 5° east of Chi (χ) Ursae Majoris. This large, bright spiral is visible in 2-inch telescopes. An odd pair of interacting galaxies, **NGC 4485** and **NGC 4490**, lies 1° northwest of the bright star Beta (β) Canum Venaticorum. The brighter of the two is NGC 4490, an irregular barred galaxy glowing at 10th magnitude. NGC 4485, a much smaller irregular galaxy, is a 12th-magnitude object. Large telescopes show these galaxies as odd-shaped blobs of light that nearly touch.

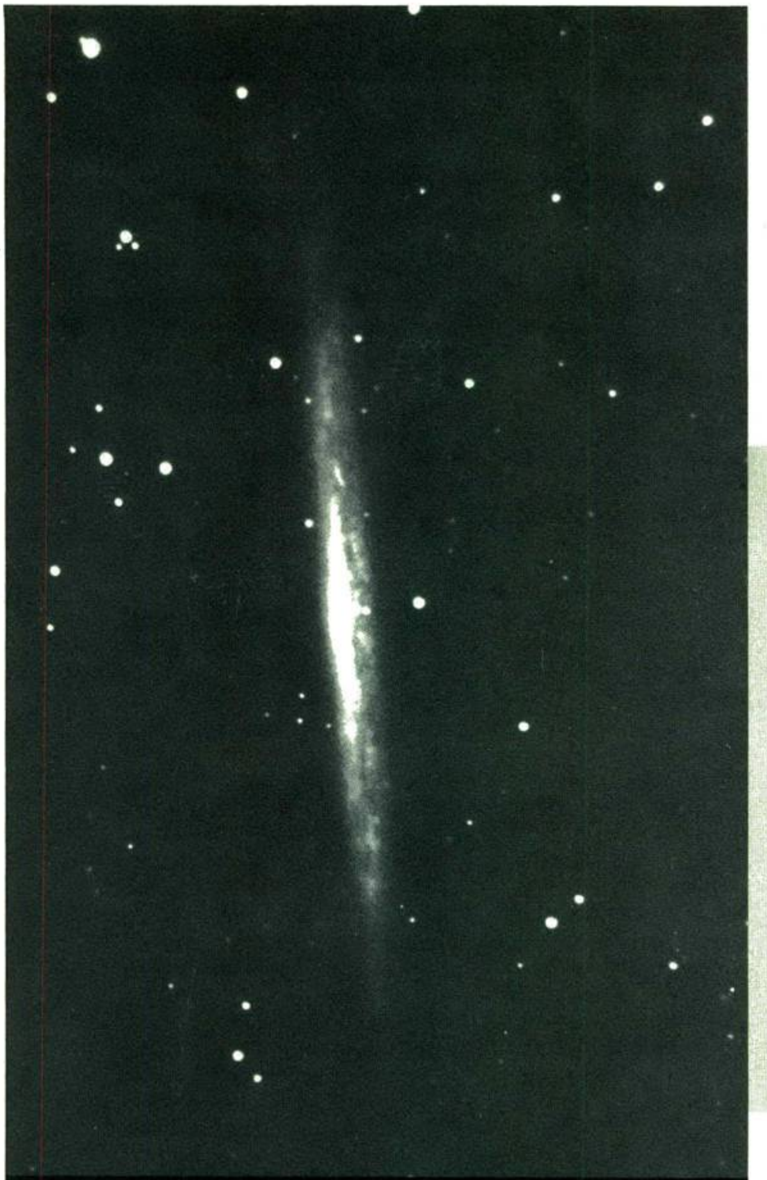
Three-and-a-half degrees east of Beta lies **M94** (NGC 4736), a face-on spiral with an intensely bright center and extremely faint, diffuse outer arms. Most backyard scopes show only M94's nuclear area: even large scopes show the arms as a faint cloud surrounding the bright center. **M63** (NGC 5055) is a magnitude 8.6 spiral with knotty arms located 5° east of M94. M63 appears like an oval smudge of nebulosity in a 2-inch telescope. In a 6-inch scope the galaxy appears like a small, bright central glow with an extremely faint oval haze surround-





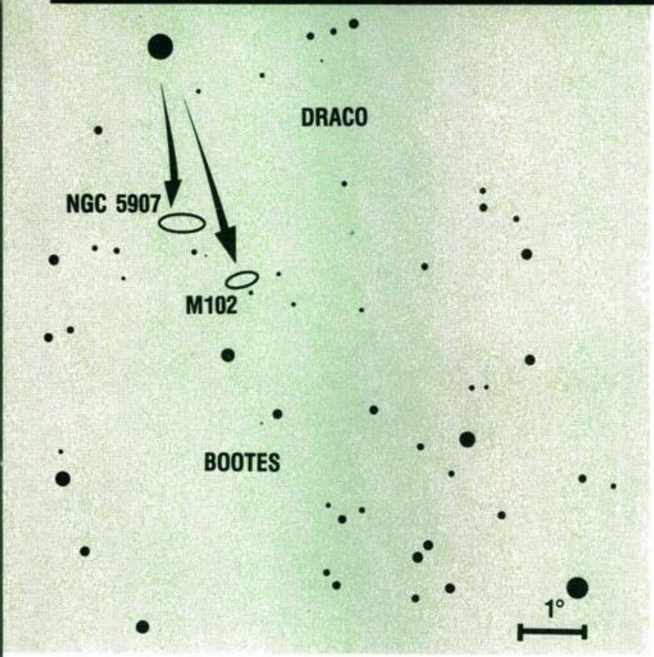
M101
8-inch f/10 SCT 100x by David J. Eicher

**ELUSIVE M101** in Ursa Major is an enormous face-on spiral with a notoriously low surface brightness. Large telescopes betray the galaxy's spiral pattern.



NGC 5907
Magnitude 10.4 12.3′ by 1.8′ by Kim Zussman

M102
Magnitude 10.0 5.2′ by 2.3′ by K. A. Brownlee



**A SLIVER OF LIGHT,** edge-on NGC 5907 is one of the thinnest galaxies visible in small telescopes. Its neighbor M102 is a bright, spindle-shaped galaxy with a featureless disk.

ing it. A 10-inch or larger telescope reveals a faint, mottled spiral pattern in the galaxy's hazy outer envelope.

**M101** (NGC 5457) provides one of the best test runs for star hopping in the entire sky. To find this big face-on galaxy, aim your scope at the bright double star Mizar (Zeta [ζ] Ursae Majoris). Move from Mizar through Alcor, its northerly companion, a distance of 2° to the 5th-magnitude star 81 Ursae Majoris. Now move east along a line consisting of 83, 84, and 86 Ursae Majoris. Just east of 86 lies a north-south line of 8th-magnitude stars. M101 lies 1° northeast of the center star in this line.

Although it is big, bright, and oriented face-on, M101 is notoriously difficult to observe because it has a low surface brightness. Observe this galaxy on nights when the sky is at its darkest and use low magnifications. A 6-inch scope shows a diffuse glow at the galaxy's position; a 10-inch scope demonstrates the galaxy's center is brighter than its outer nebulosity.

Another pair of galaxies is that composed of **M102** (NGC 5866) and **NGC 5907** in Draco. M102 is a lens-shaped galaxy glowing at 10th magnitude and measuring 5.2′ by 2.3′. Although it is bright, M102's appearance changes little from telescope to telescope. More exciting is its neighbor NGC 5907, located 2° northeast, one of the sky's best edge-on spirals. Even a 2-inch telescope shows this as a thin streak of light. Large backyard scopes reveal a thin dust lane bisecting the galaxy lengthwise.

Each of the galaxies we have surveyed is bright because it is close to us in space. Among the nearest galaxies beyond our own galaxy group are M81 and M82, which lie approximately 10 million light-years away. Although this sounds like an enormous distance, it is in our backyard as galaxies go. M51 is barely twice as distant, lying some 25 million light-years off. The most distant galaxy we've looked at is M109, which lies nearly 50 million light-years distant. That amateur astronomers can detect the faint barred spiral arms of M109 is testimony to the quality of backyard telescopes and the skill of amateur observers. □

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*Alan Goldstein is national coordinator of the National Deep Sky Observer's Society. He is also curator of science at Louisville's Museum of History and Science.*

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# How to Observe Planets during

With this step-by-step guide to daytime polar alignment you'll be able to locate planets and stars when the Sun is up.

by Joe H. Palmer

Astronomy doesn't have to happen only at night. During the day you can spot bright planets like Venus, Jupiter, and Mercury. It's something you might not ordinarily think of doing, and it's fun to do.

There's only one roadblock to daytime observing: knowing where to aim your telescope. It's relatively easy to find planets with a fork-mounted telescope equipped with setting circles, because all you need to do is set your circles to the coordinates for any given planet. However, the telescope must be accurately aligned with the north celestial pole.

The best method is to align your telescope the night before and simply leave it undisturbed. (See "Easy Steps to Perfect Polar Alignment" by Robert Burnham, August 1982.)

If you can't leave your telescope set up outside, there is a way to align the scope during the day. In essence you turn the usual procedure backwards. Instead of accurately aligning on the pole, you roughly align on the pole and then use an object of known position on the other side of the sky — the Sun — to check your accuracy. After setting the elevation of the polar axis to your latitude, you fine-tune the azimuth of the polar axis by trial and error. It normally takes two or three iterations of this last step.

First, you need the right ascension and declination coordinates of the objects you want to find. Look up the positions of the Sun and any planets you want to see for the time you will be observing. The best source for this is the *Astronomical Almanac*, a compilation of planetary positions and data published each year by the U.S. Government Printing Office.

Let's say you want to find Venus at 3 p.m. EST on March 3. The *Almanac* gives the positions of the Sun and Venus for March 3 at 0 hours universal time (UT), and 3 p.m. EST corresponds to 20 hours UT, or 20/24 of the way between 0 hours UT on March 3 and 0 hours UT on March 4. The coordinates you want lie 20/24 of the way between the *Almanac*'s positions for March 3 and March 4. Write them down and have them handy at the telescope.

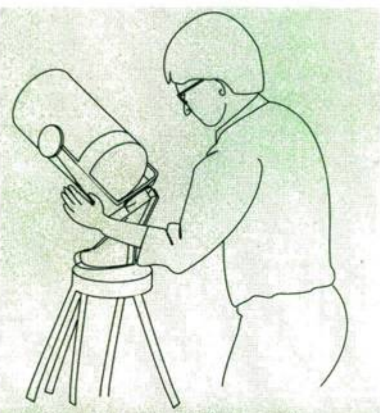
Set up the telescope with the polar axis pointing north. Roughly align it using a magnetic compass or set up parallel to a north-south street grid.

Now set the elevation of the polar axis. To do this, set the latitude of your observing site on the telescope's declination setting circle. (Point it north of the celestial equator.) Lock the declination axis. Rotate the scope's fork arms until the declination axis is horizontal. Ensure that the declination axis is horizontal by placing a carpenter's level across the fork arms and using the right ascension slow-motion control to level the arms.

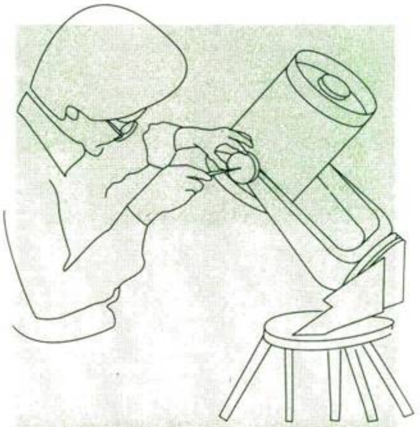
Set the carpenter's level parallel to the tube and raise or lower the elevation of the polar axis until the level shows the telescope is pointed exactly at the zenith.

Next, fine-tune the azimuth of the polar axis. If you're using the Sun, cover the main telescope and place a solar filter over the finder scope. Never look at the Sun directly. Using the coordinates from the *Almanac*, set the telescope to the Sun's declination and then swing the scope in right ascension over to the Sun. If you miss the Sun in the finder's cross hairs, lock the telescope at the closest point it reaches.

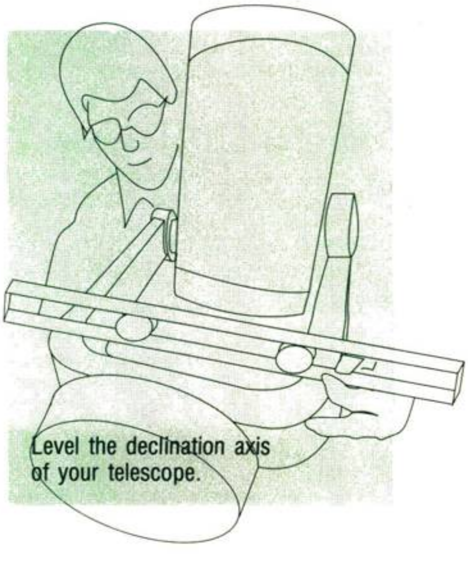
Move the polar axis in azimuth until



Aim your scope north for rough polar alignment.



Set the declination circle to read your latitude.



Level the declination axis of your telescope.

# the Day

the Sun is again nearest the cross hairs. If necessary, repeat the steps, moving first in right ascension and then in azimuth until the Sun reaches the center of the field of view.

When the Sun lies in the finder scope's center, set the right ascension setting circle on the Sun's current right ascension. Lock the telescope in place. The task is now complete: the telescope is polar-aligned.

You're now ready to offset to the planet or star. Unlock both axes of the telescope and slowly move to the correct right ascension, then declination of the new object. The planet should appear in your finder scope — or, if you've done a very accurate job, even in your main telescope. If it doesn't, repeat the alignment procedure and you will increase its accuracy. At the very worst you should have the bugs worked out after two or three tries.

Once you've mastered this technique, you'll begin to appreciate that nighttime isn't the only time that you can do astronomy. ☐

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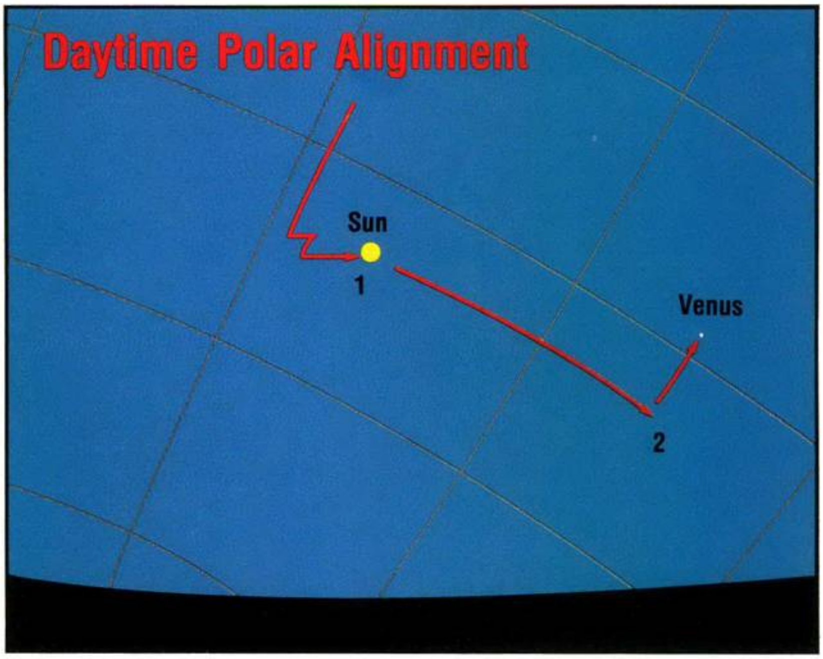
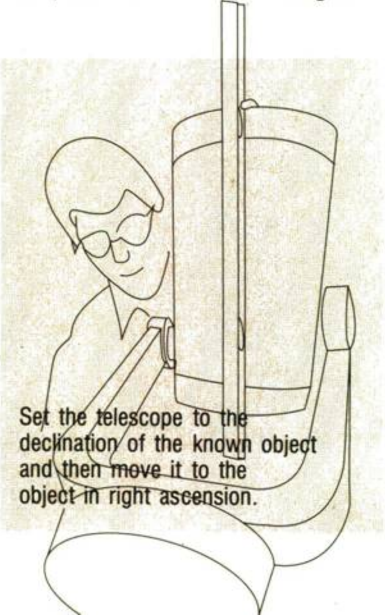
*Joe H. Palmer, an amateur astronomer, lives in Seattle, Washington.*

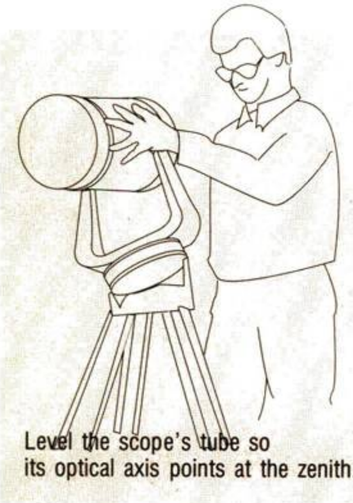
**VENUS BASKS** in pale blue during an afternoon in May 1988. Photo by Mark Payne-Gill.



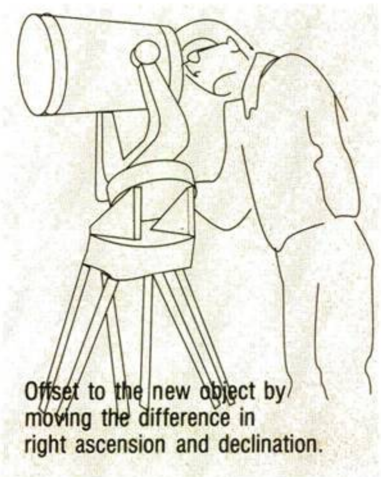
**FIND DAYTIME PLANETS** by using an object with a known position to fine-tune alignment (1). After aligning, offset to the coordinates of an object you want to observe (2).



Set the telescope to the declination of the known object and then move it to the object in right ascension.



Level the scope's tube so its optical axis points at the zenith.



Offset to the new object by moving the difference in right ascension and declination.

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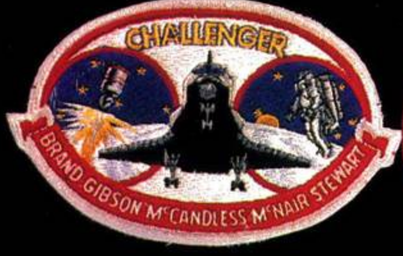
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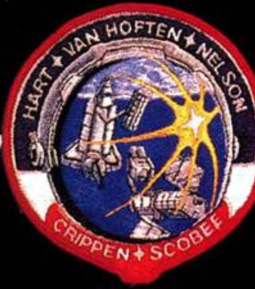
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CRIPPEN ✦ SCOBEE

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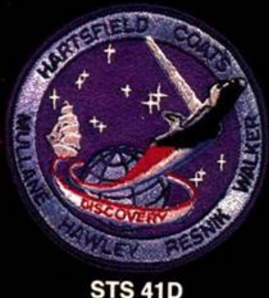
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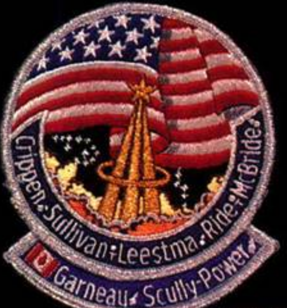
Crippen · Sullivan · Leestma · Ride · McBride
Garneau · Scully-Power

**STS 41G**
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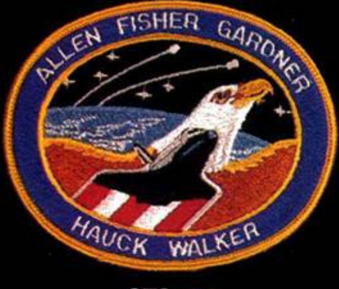
ALLEN FISHER GARDNER
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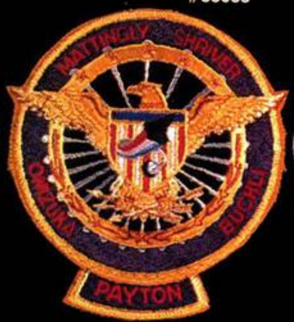
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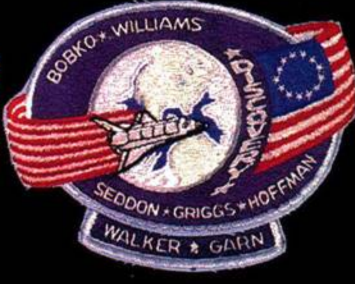
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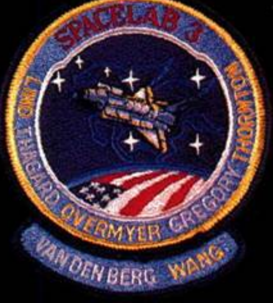
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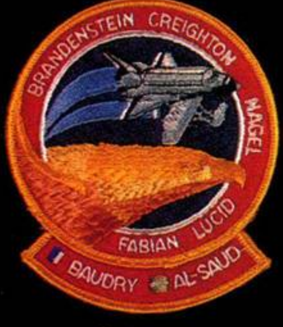
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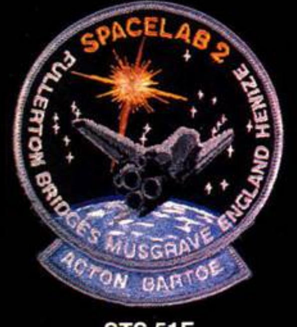
SPACELAB 2
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ACTON BARTOE

**STS 51F**
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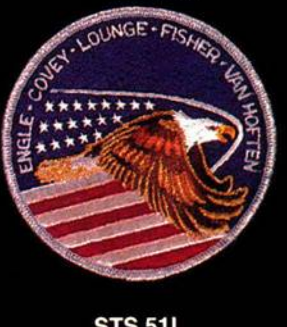
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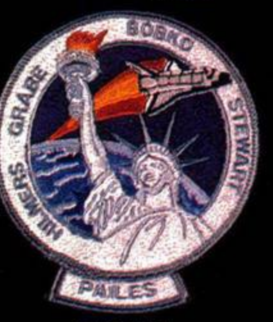
**STS 51I**
#35071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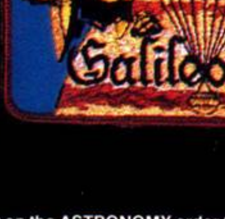

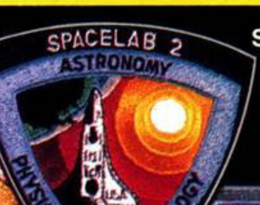
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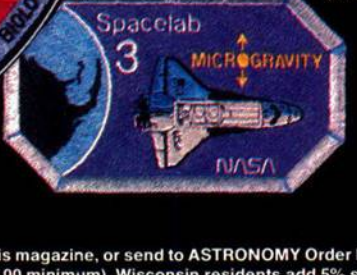
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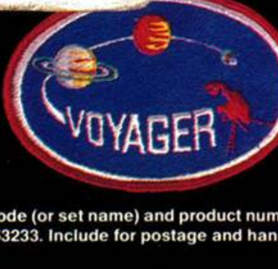
MICROGRAVITY
NASA



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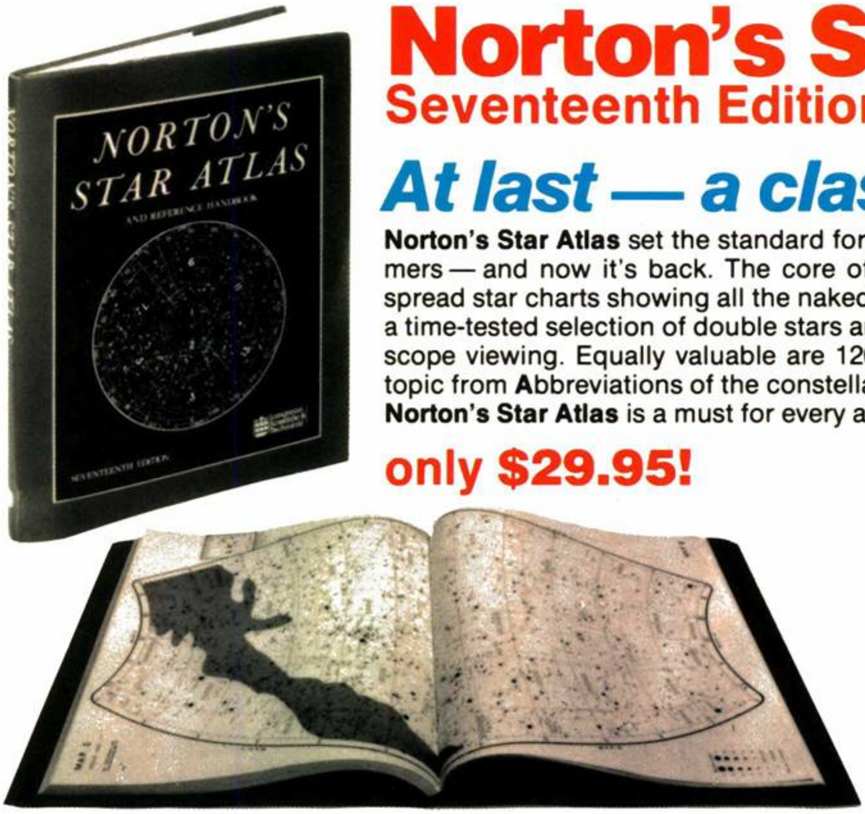

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# CAPTURING MARS ON PAPER

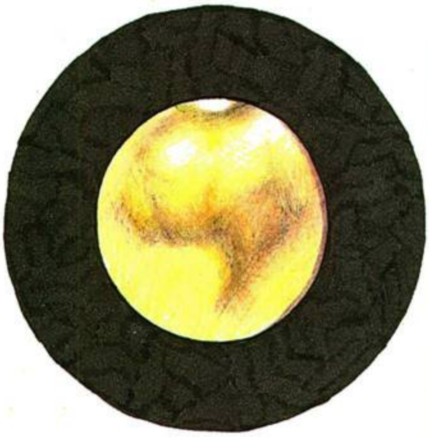
One of the by-products of the 1988 Martian opposition is that dozens of observers went outside with telescopes, put pencil to paper, and recorded the images of Mars they saw at the eyepiece. ASTRONOMY received many observing reports that included drawings of the Red Planet made with instruments ranging from binoculars to a 31-inch reflector.

"I began my night's observing as usual, unprepared for the surprise to come," wrote James S. Mullin of Braintree, Massachusetts. "On September 23 I got ready to observe Mars with my 8-inch f/10 SCT. I wanted to experiment with magnifications to see as much detail as I could on the planet's surface.

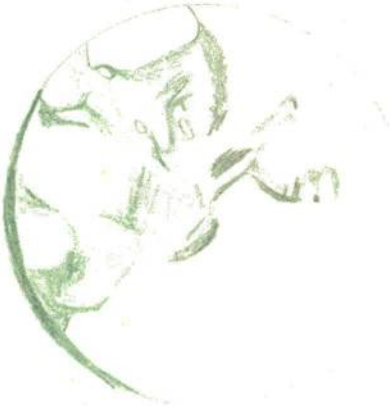
"As soon as I focused on the planet," Mullin continued, "I was startled to see a bright star near the planet's limb. Over the next few minutes I could see that Mars was moving toward the star. A few more minutes of watching convinced me the star would be occulted. Luckily I had sketching supplies with me, and I drew a number of circles so I could record the occultation as it happened."

Mullin began watching the planet shortly before it occulted the 7th-magnitude star 11 Ceti. "At 11:13 p.m. EDT the star blinked off behind the Martian limb," he reported. "The seeing was pretty lousy and I wasn't sure my watch was accurately set. I began fiddling around and missed the star's re-emergence. But I saw it at 11:30 p.m., just after it popped out from the other side of the planet. At this moment the star lay on the other side of the South Polar Cap — it was incredible!"

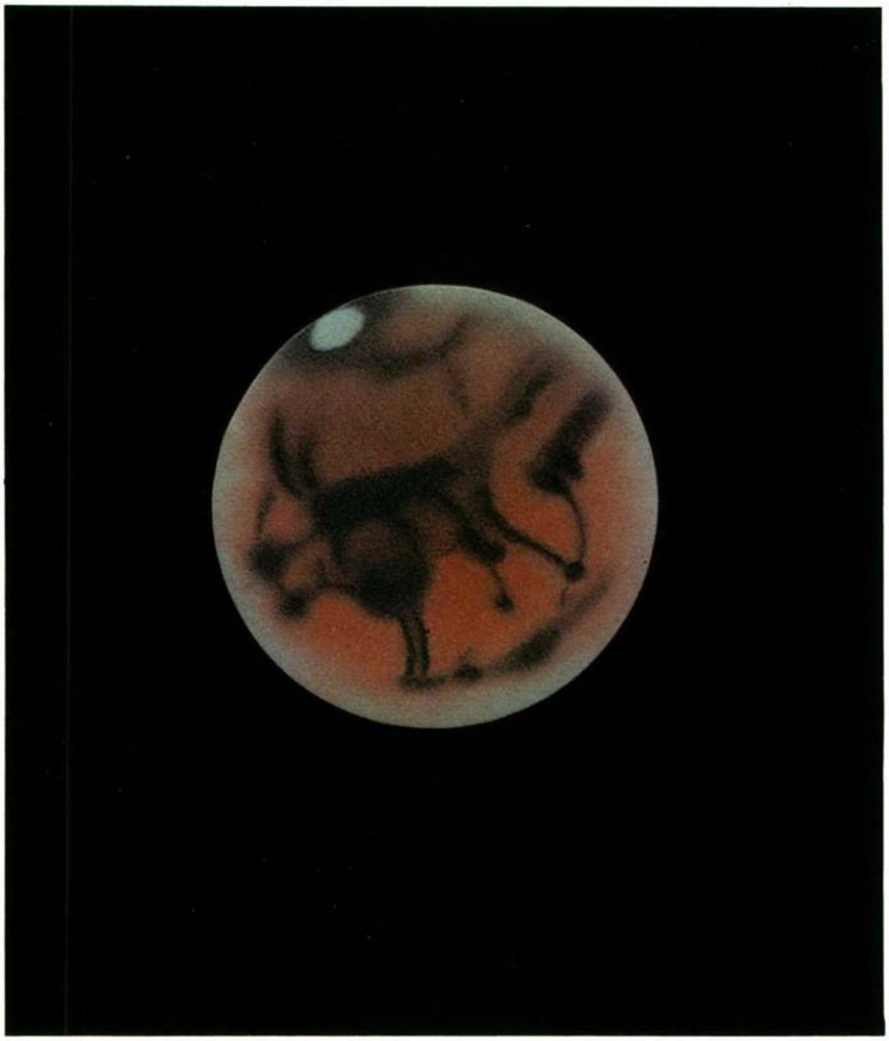
A Martian occultation like the one seen by Mullin is a rarity — most observers concentrate on simply viewing the planet's surface. In Bedworth, England, Ivor L. Clarke viewed Mars throughout the opposition and was pleasantly surprised that he could see the planet so well with a 4-inch telescope. "My scope is a 4.5-inch catadioptric reflector on an equatorial mount," he explained. "I normally use a magnification of 250x, which must be about the useful limit. I observe the planet from my back garden, just a short distance from Bedfordtown center,



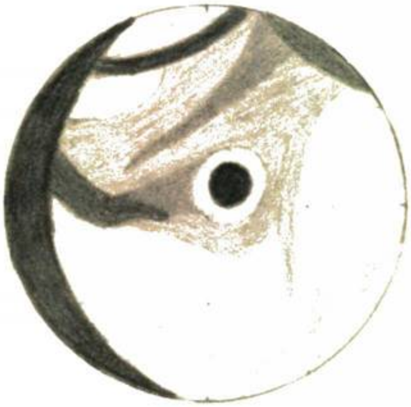
**SMALL TELESCOPE VIEWS** of Mars showed an impressive amount of surface detail during 1988. Sketch made with a 4-inch telescope by Ivor L. Clarke.



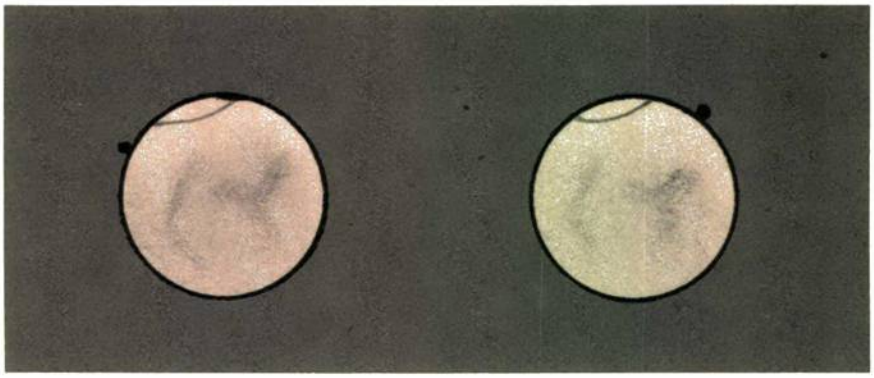
**LARGE TELESCOPES** revealed dazzling Martian detail, "more than could be drawn," according to one observer. Sketch made by Robert Bunge with a 31-inch telescope.



**MARS DURING GREAT SEEING** shows detail reminiscent of the "canals" reported by nineteenth-century observers. Sketch by David L. Graham.



**THE "EYE OF MARS,"** Solis Lacus, was prominently visible throughout the 1988 opposition. Six-inch telescope sketch by Robert Albertson.



**MARS OCCULTS A BRIGHT STAR** in this pair of sketches made on September 23, 1988. Sketches by James S. Mullin.

which has quite a few lights. Surprisingly, on cold, frosty nights, I can see a surprising amount of detail on the Martian surface."

In sharp contrast Robert Bunge of Columbus, Ohio, used the 31-inch f/7 reflector at Warren Rupp Observatory to watch Mars. According to Bunge, "On August 21, Tom Burns, Barrie McConnell, John Boggs, and I noticed a detachment of the South Polar Cap at Martian longitude 290° and latitude 80°. We also noted a sharp, dark line projecting into the cap. We used a variety of magnifications on the telescope, including 225x, 340x, and 541x.

"The planet's disk showed a great amount of detail," Bunge continued, "as the seeing was rock steady. Syrtis Major was disappearing into the terminator while Sabaeus Sinus showed too much detail to realistically draw. We noticed a great amount of detail in the Hellespontus and Yaonis regions, areas that appear to link with the polar cap."

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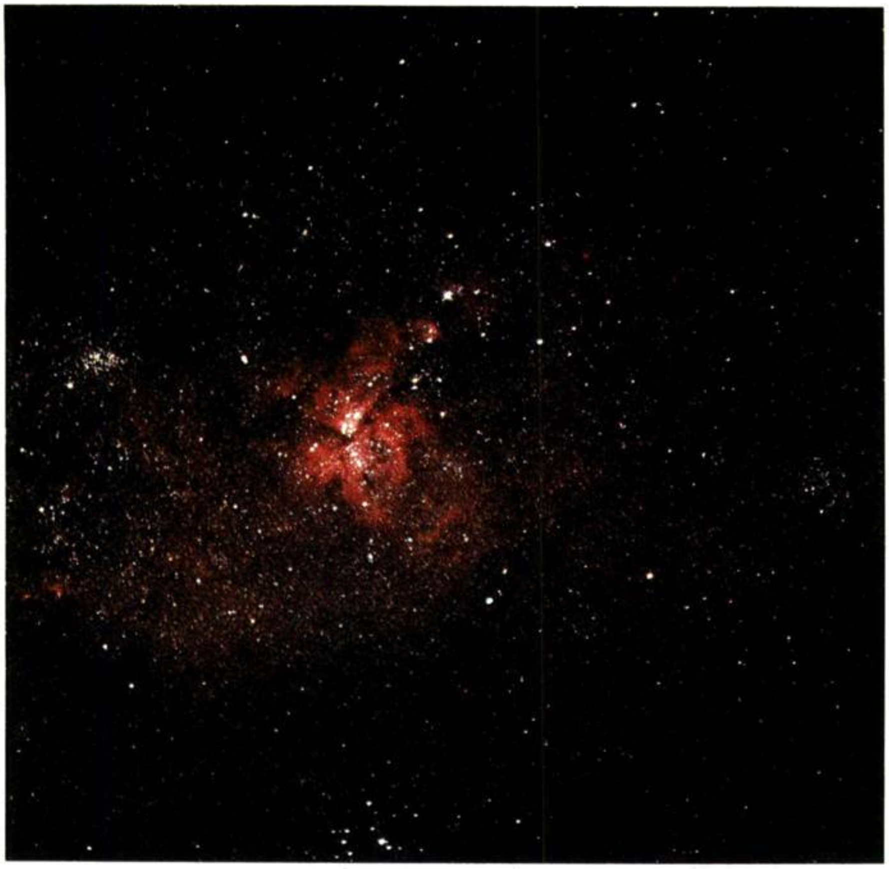
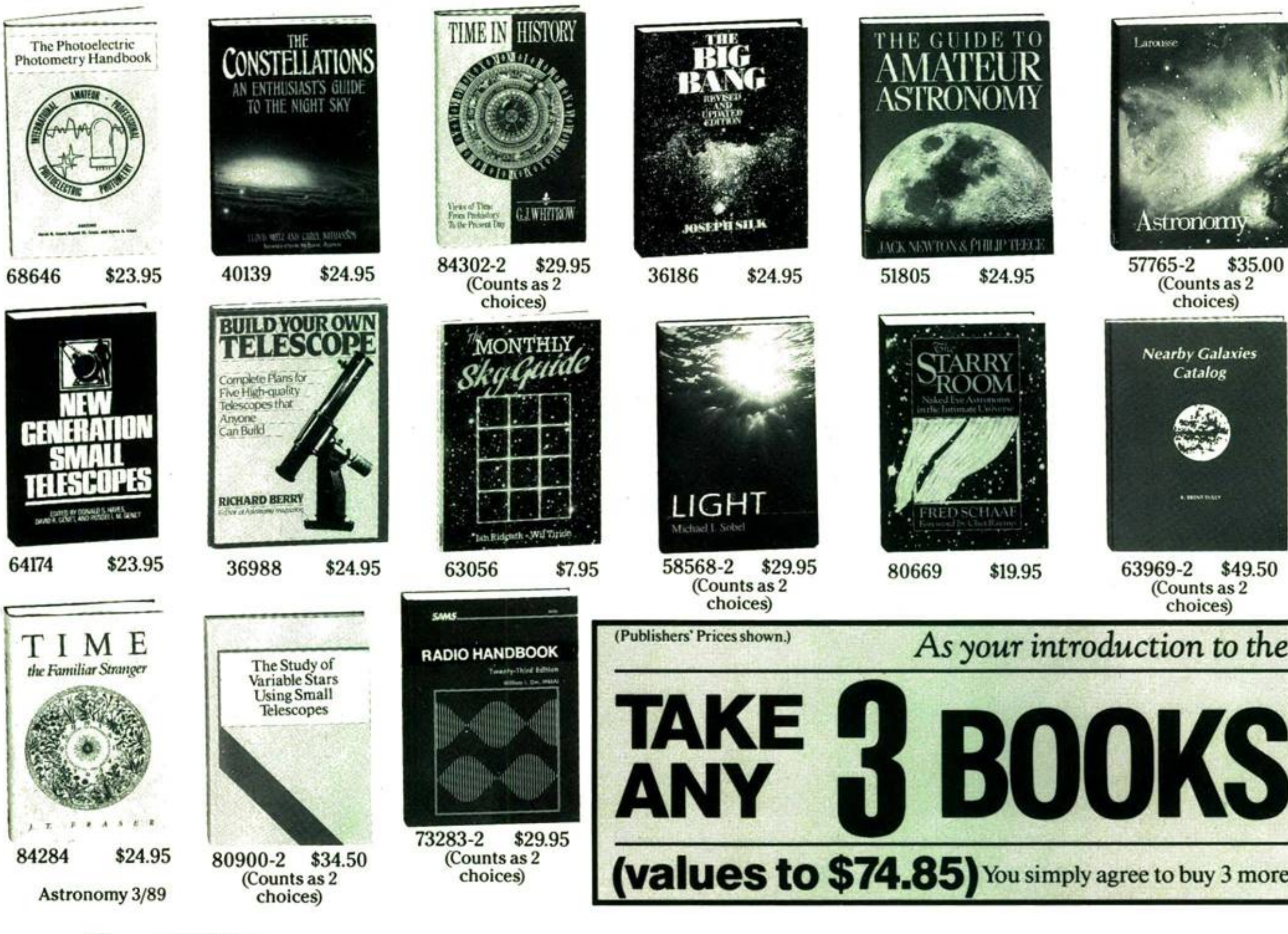


## A POLYNESIAN ODYSSEY

"I was astonished! That's all I can say!" Lynn R. Hammond was reacting to reading about Ivan Dryer's astrophotography trip to Bora Bora, Polynesia (Reader Reports, November 1988). "At the very same time Mr. Dryer was photographing the southern sky, I was doing my own astrophotography about an hour away on the island of Moorea."

A resident of Anchorage, Alaska, Hammond took a Takahashi Sky Patrol camera mount and numerous rolls of Konica 3200 film on a Polynesian odyssey in April 1988. Hammond explained that careful preparation was necessary: "Before I left Alaska, I carefully set the camera mount so that when the tripod head was exactly level, the mount was at a 17.5° angle — the latitude of Moorea. Thus, when I arrived, I could begin shoot-

**SPLENDOR OF THE SOUTH,** the Eta Carinae Nebula glows brilliantly in a 135mm f/2.8 telephoto lens photo made from Moorea, French Polynesia. Lynn R. Hammond photo.



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"Still, polar aligning the mount was tricky," said Hammond. "I found a dimly lighted buoy a few miles due south of a pier on the island and used it to help find Sigma Octantis, the brightest star near the south celestial pole.

"Once I was properly aligned," Hammond continued, "the photography was easy. I spent several hours shooting and reshooting everything between Centaurus and Canis Major, alternating between a 50mm and 135mm lens. As I waited during exposures, I scanned the sky with binoculars. Much to my delight, supernova 1987A was visible, as were many other legendary objects of the southern sky: the Coalsack, Eta Carinae, Omega Centauri, NGC 5128, and many others. I was like a kid in a candy store!"

Hammond highly recommends a trip to the Southern Hemisphere for northerners. "It was an eye-opening experience, and in hindsight I felt rather incomplete not having seen the southern sky's wonders. Polynesia was terrific — the only problem happened back in the States, at the airport in Los Angeles. The x-ray image of my guidescope looked like a pipe bomb, and I had to give the standard talk: 'You won't believe this, but I'm an astronomer . . .'"

## OF WILDFIRES AND SUNSPOTS

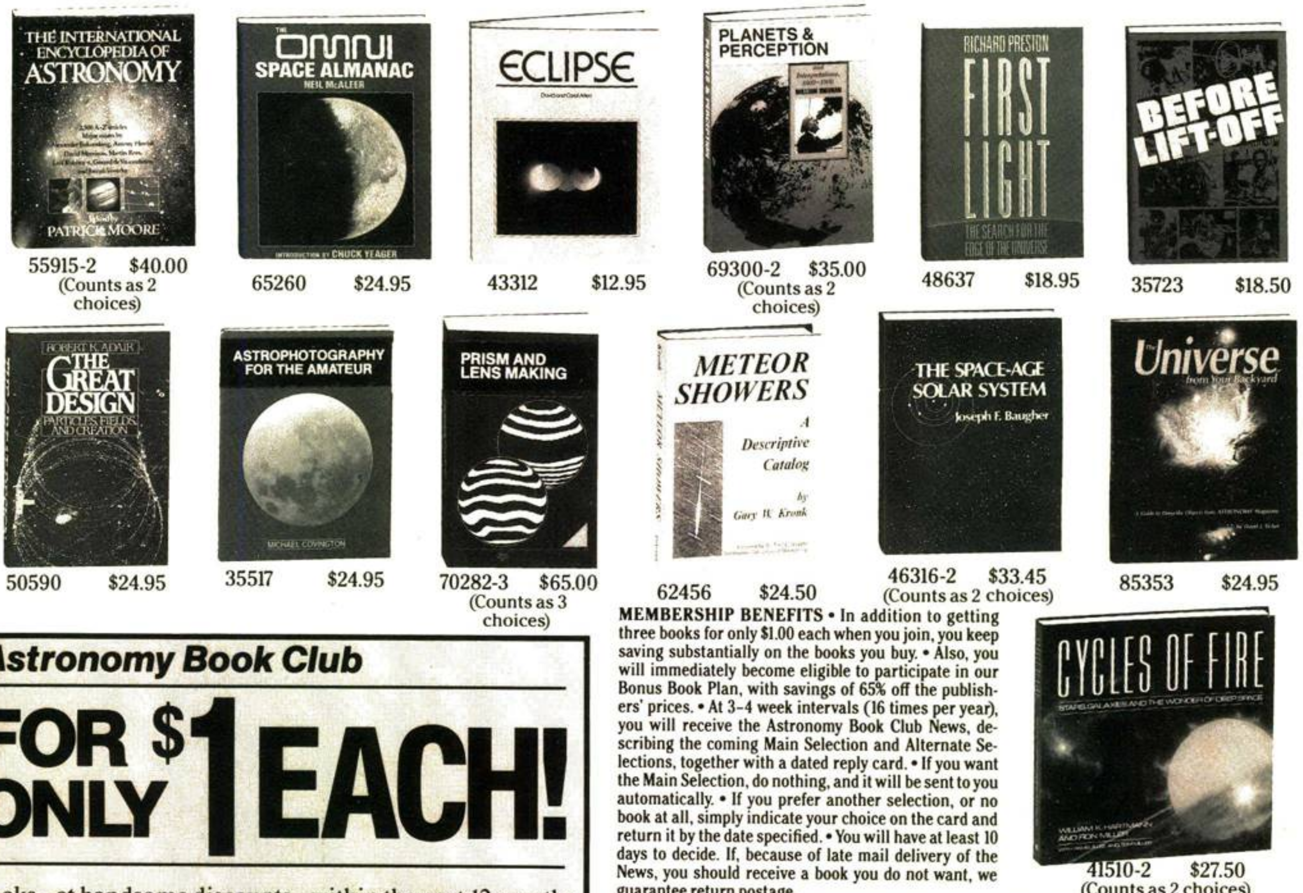
"Nineteen eighty-eight may be the worst year for wildfires in U.S. history," said Tom Ritland of Salt Lake City. Throughout the dry summer of 1988, fires in the western United States ravaged tens of thousands of acres of timber, including large parts of Yellowstone National Park. The hazy smoke produced by these fires lingered for weeks in the western United States and caused some unusual effects for observers of the Sun.

"Although the fires did considerable damage," Ritland continued, "their smoke made it very easy to see naked-eye sunspots. Near Salt Lake City smoke from the Yellowstone fires created dramatic, fire-engine-red sunsets and sunrises. Each morning and evening as the Sun approached or rose above the horizon, the Sun's disk slowly became a beautiful shade of red. Sunspots were routinely visible to the naked eye."

**NAKED-EYE SUNSPOTS** were easily visible last September because of smoke from the summer's western fires. Photo by Tom Ritland.

Ritland explained that he "saw many large sunspots in binoculars during periods of extraordinarily dense smoke coverage. However, no one should ever look at the Sun with binoculars under normal conditions." — *David J. Eicher*

*ASTRONOMY welcomes submissions of observations, photographs, telescopic drawings, and brief articles for possible inclusion in Reader Reports. Send your reports to: ASTRONOMY Reader Reports, 1027 North 7th Street, Milwaukee, WI 53233. Reports may be edited for length and clarity.* ☐



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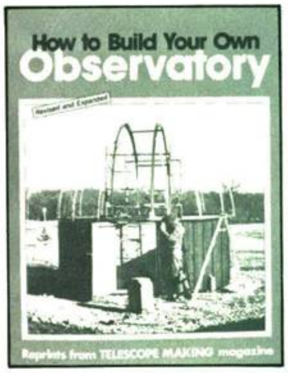

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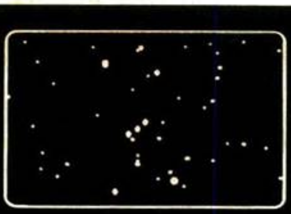

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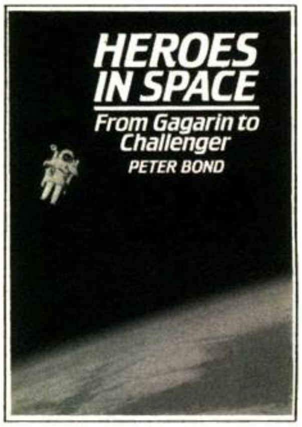

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# Forum

## ASTRONOMY ONE STEP AT A TIME

Astronomy is an awe-inspiring pastime. There are so many magnificent sights to enjoy that I was eager to experience all of them when I first began stargazing. But as I got deeper into astronomy, I realized I couldn't possibly see and appreciate everything at once. Instead, I found that with persistence I could experience the wonder of the universe one discovery at a time.

Like many young amateurs, I was so excited about beginning my exploration of the universe that I didn't realize the inexpensive 40mm refractor I bought was hardly suited to the task. Needless to say, my first planetary views with that telescope weren't what I expected.

But I persisted. Soon I replaced my little refractor with a more practical pair of 7x50 binoculars and discovered a whole new world. Suddenly the night was filled with hundreds of misty tendrils of light, the tenuous clouds that filled the space between the stars. It intrigued me that even as I watched new stars were forming beneath the gossamerlike folds of interstellar matter.

I became obsessed with nebula watching. With my trusty binoculars, I cataloged as many of the Messier objects as I could from 26° south latitude in Australia. One night as I was casually sweeping my 7x50s low in the north, I came upon an object that astounded me and led me to a decision.

It was unlike any nebula I had ever seen. Though nebulalike in color, this object was definitely elliptical, a pale yellow-green oval surrounded by the great cosmic dark. I poured over my star charts until I discovered I was looking at M31, the Great Galaxy in Andromeda. I raced back outside and carefully swept the area with my binoculars until I again located the object.

But something was wrong. No matter how carefully I focused the binoculars, the great spiral arms I had seen so magnificently displayed in photos remained invisible. There and then I decided I needed a telescope that could show me what I wanted to see.

This time, though, I was determined to do things right. I decided how much I could spend, which wasn't much because I was in my first year of high school. Then, after wavering between a reflector for observing nebulae and a refractor for planets, I bought a 4.5-inch f/9 Newtonian reflector.

Finally, after what seemed like years of waiting, I brought home my new prize possession. I carefully unpacked it and put it together. As luck would have it, that night was rainy.

The weather was clear the next night, and I hurried outside to test my new telescope. First on my observing list was an old favorite, M42. I lined up the finder on the middle "star" in Orion's sword. There, shining with a steady greenish light, was not just a fuzzy, irregular blob of light but a well-defined image of incredible beauty, a stellar birthplace. There was none of the dramatic red and blue I had seen in photos, but the incredible detail I saw more than compensated for that.

I zeroed in on the densest part of the nebula, and there was a group of four tightly packed stars. It was the Trapezium, one of the most famous groups of young stars. I was witnessing the birth of stars that might one day give life to countless other life forms.

From that moment on I've been hooked. Though I've realized with some regret that even with my new scope the spiral arms of M31 will remain invisible, that doesn't deter me a bit.

With my little reflector I've viewed sights that have taken my breath away and lifted my soul. I've seen things to which all of humanity is inexorably linked. When I'm out with my scope, I feel somehow connected to a greater plan. — *Mark J. Finn*

## 'EXPOSING' A COMET

The day started innocently enough. I was doing some routine tasks at the photo lab where I work when someone noticed a tiny blur near the arm of M51 on an astrophoto I had just taken. It was the very likeness of a comet, and it appeared to be moving north-south, which is rare for comets.

I'm an experienced lab technician, so I knew the negative was not defective. This was an important discovery, or so I thought.

My approach to amateur astronomy had been mostly aesthetic up to this point, stargazing and taking astrophotographs for my own enjoyment. Now I suddenly had done something that was important.

I decided to photograph the object again that night. I loaded my massive Schaefer mount, the pedestal, the C14, clothing, electronics, food, and charts into my van. My astrophotography partner Daphne and I drove for two hours to a mountaintop so we could get good shots. Because very precise polar alignment was important to keep all the stars round at the edge of the field, I spent several hours "drifting." Just as the guide star stayed put on the line, a terrible yell came out of the van. Daphne had scalded her leg with hot coffee.

As the Moon dropped, I tried to find the area of sky the object was located in. Setting circles were not accurate enough, so I spent half an hour carefully star hopping to the place. I opened the shutter and shot for an hour. Anything that moved during that time would show up as a blur. The exposure finished, I moved to the other place the "thing" might be located (it could be moving in either direction) and repeated the procedure.

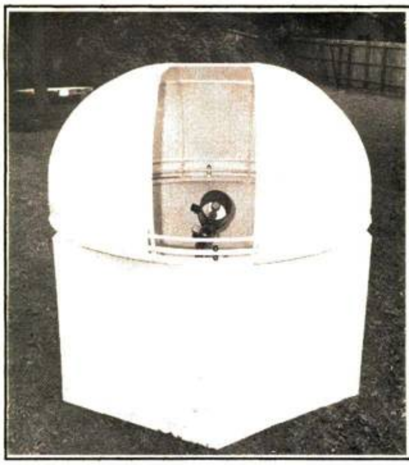
When the two precious exposures were completed, it was 4 a.m. Daphne managed to sleep with her burnt leg, and I drifted into an uneasy nap. At 6 a.m. we quickly threw everything back into the van and raced down the mountain.

I processed the film as soon as we got home and found nothing. No blur. Just some galaxies, a satellite, and some dust on the negative. I felt I had failed. A lot of effort for nothing.

I got to work several hours late that morning. Glances from a number of my coworkers informed me that astronomy was not a universally supported avocation.

I again looked at the picture that started all this, a nice photograph of M51. There was the "thing" all right. Out of curiosity I picked up a color negative I had made earlier of M51, expecting to find blank space where the "thing" was. But there it was! And there it was on another negative and another!

The "thing" turned out to be a galaxy. As comet-discoverer Carolyn Shoemaker said, "Those little galaxies can sure disguise themselves as comets!" I agree.
*— Tony Hallas and Daphne Mount* ☐



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## Astronomy Books

# THE ART OF NAKED-EYE OBSERVING

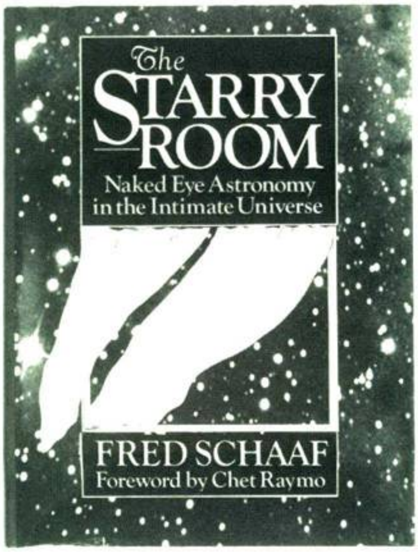
*The Starry Room* by Fred Schaaf, (John Wiley & Sons, 1988), ISBN 0-471-62088-2, softcover, 224 pages, $19.95.

If Fred Schaaf had his way, everyone would spend the nights out under the stars and the days looking for unusual solar events. His enthusiasm for naked-eye observing is infectious. He points out so many phenomena to watch for that you can spend many enjoyable hours observing the sky shows and not see all the things he writes about. Most of us miss these celestial happenings simply because we are not paying attention to them or do not know what to look for. This book is loaded with tips on when to look up.

We are all familiar with rainbows. Schaaf tells you how to look for about one hundred types of rainbows, including secondary ones, rainbows with Alexander's dark band, double rainbows, third-order rainbows, full circle rainbows, reflection rainbows, and Jearl Walker's dozen rainbows in a drop of water. Diagrams help to explain the causes of some of these rainbows.

A large portion of the book is devoted to the author's experiences of viewing lunar eclipses, meteors, fireballs, and Halley's comet. He encourages you to be on the lookout for meteors and fireballs and to try to observe any comet that comes our way.

In another chapter he covers in simple terms the workings of the human eye. You can see objects that are much dimmer than you thought and he tells you how to test the limit of your naked-eye ability to see faint stars. The target for this test is the keystone pattern in the constellation Hercules. By using averted vision (looking a little bit away from a dim object), you can see it better. This happens because of the location of low-light receptors in the retina called rods. Most rods are located away from the central focus of the retina. By looking to one side of a faint object, you focus most of the low-light image on the rods.



Schaaf laments the end of star-filled skies. In the last century we have become the first people to study the heavens with sophisticated instruments and yet, because of light pollution, we are fast becoming the last generation to view dim stars. As cities grow, so grow the light pollution and the uselessness of optical telescopes near the cities. The effects of worldwide light pollution make it very difficult for many people to really see the night sky in all its glory. Schaaf calls on all astronomers and stargazers to work with their local government officials to promote the use of outdoor lighting that reduces the pollution.

The title for this book comes from the chapter on how to paint starfields on a ceiling. With star charts as your guide and phosphorescent paint you can create a sky that glows in the dark. How about adding a comet or two, or even the Orion Nebula to your indoor sky? These are some of the author's suggestions for enhancing your starry room.

I found this book a joy to read. How many times have you picked up a novel, planning to spend only a few minutes reading a few pages, but the book was so interesting that several pleasurable hours passed instead? This can easily happen with this book. Schaaf's style is informative and relaxed. His use of subtle humor in describing his trials and tribulations in glimpsing a comet or meteor gives the book a personal feeling. I felt like an old friend was telling me a story. I think you will also enjoy this book and will find a place for it on your astronomy library shelf. — *Robert A. Garfinkle*

### A COSMOLOGICAL PUZZLE

*The Dark Side of the Universe* by James Trefil, (Scribner's, 1988), ISBN 0-684-18795-7, hardcover, 197 pages, $17.95.

Despite a title that hints at murky byways where astronomy meets mysticism, this book delves into modern cosmology by focusing on the "missing mass" or "missing light" problem that is occupying many cosmologists' thoughts.

Trefil begins by recapitulating the history of cosmology. After sketching the geocentric universes of the ancients, run by spirits or gods and having much emotional warmth but little intellectual strength, Trefil proceeds rapidly through the Copernican revolution to the advent of modern observational cosmology in the 1920s. Next comes a review of the Big Bang's main stages, which leads him to a fundamental cosmological problem of today: how did the universe manage to make galaxies? Trefil points out in a chapter called "Five Reasons Why Galaxies Can't Exist" that whatever kind of answer eventually solves this question, it is not obvious or clear-cut.

From this Trefil makes a short hop to the topic hinted at in the book's title. What if, he asks, there is more matter in the universe than just the visible stuff? Trefil admits that piling one more complication onto the problem may seem like intellectual masochism. But he reminds us that sometimes adding another puzzle piece can be the essential step that makes the whole pattern click into place.

The evidence for dark matter is strong, however indirect. For example, without some form of dark matter governing their structure, spiral galaxies could not have the form they do. Trefil then shows how adding more mass — up to roughly one hundred times what s visible — can make various cosmological problems far more tractable.

Yet what *is* this dark stuff? This is where theory appears to take a big step into never-never land. Strange particles — as-yet unseen, unwanted (except by one theorist or another), and barely believable — have been postulated to fill the universe. For instance, if you don't like massive neutrinos, maybe you'd prefer the WIMPs — weakly interacting massive particles — that have been proposed.

This is more or less where the book stops. Trefil wraps up by sketching some of the ideas that may bring closure to the theories, but a lot of loose ends are left dangling. One thing's for sure — this is no field for anyone who demands tidy conclusions! And it sure helps you understand why cosmology is such a hot topic among astronomers these days. — *Robert Burnham*

### *BIG COINCIDENCES IN THE UNIVERSE*

*The Symbiotic Universe* by George Greenstein, (William Morrow, 1988), ISBN 0-688-07604-1, hardcover, 255 pages, $18.95.

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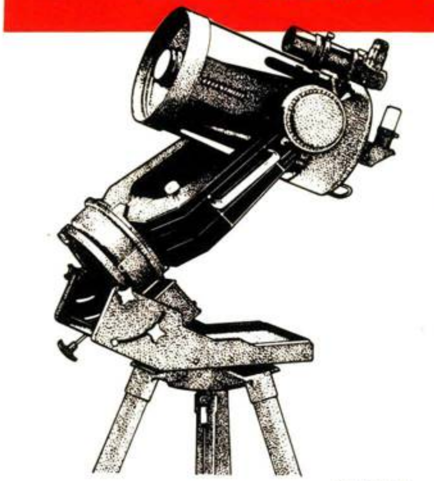

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utterly astonishing thing," writes George Greenstein, an astrophysicist at Amherst College.

He starts off by spinning some grippingly vivid scenarios in which all life on Earth is extinguished by random cosmic events. Each of these scenarios has a fair likelihood of happening at any time — past, present, or future. Marveling that life has lasted until now, Greenstein is appalled at the many coincidences that could have snuffed out all life or at least made it impossible to exist. He likens our existence today to that of a man who survives a firing squad because every rifle misfires.

That's the prologue. The rest of the work explores each of the big coincidences — misfiring rifles, if you like — that turned out just right for us. For example, another star could have collided with the Sun or (just as bad) swung close. Either way, Earth would have been destroyed or rendered uninhabitable.

If red giant stars couldn't create elements, the universe would be just hydrogen and helium. Again, no Earth and no life. If the charges of the electron and the proton weren't opposite and precisely equal, atoms couldn't exist. If water didn't have its unusual properties, life couldn't happen. If space had less than three dimensions .... If the Big Bang hadn't been perfectly smooth ....

In the end, Greenstein stacks important coincidences in a sequence and explores their uniqueness. In the course of this he ranges across a lot of scientific territory and imparts information on topics as varied as the Big Bang and biology. The explanation is written clearly and well, and any lay reader will enjoy the story.

But a prospective reader should know that the book's philosophical stance is not wholly accepted by other scientists, to say the least. Reduced to its essence, *The Symbiotic Universe* is a dramatic exposition of what is known as "the anthropic principle." This principle can be expressed in several ways, but it generally says that our very existence determines the design of the universe.

At first reading this principle sounds deep and significant. It has great appeal for anyone who wants to believe people somehow have a favored place in the universe. But the more you dig into it, the closer the principle comes to a tautological banality: we observe a certain kind of universe because that kind of universe is structured in such a way that we can exist to observe it.

Well, so what? Where does this take us? Many have found it hard to see how such a principle helps us think meaningfully about the universe. It affords endless scope for debate, but that's exactly what's wrong with it. The majority of cosmological researchers have found the anthropic principle too open-ended and lacking in decisive tests to be useful.

On the other hand, Greenstein is a very engaging writer and he certainly makes his points as well as anyone could. You may not be convinced, but you will have an entertaining and thought-provoking read. — *Robert Burnham*

## FOR STUDENTS OF ASTROPHYSICS

*Astrophysical Concepts*, second edition, by Martin Harwit, (Springer-Verlag), ISBN 0-387-96683-8, hardcover, 626 pages, $54.

This is a popular book among professional astrophysicists, produced with that meticulous attention to detail and completeness characteristic of the house of Springer. In his preface Harwit states that the book is based on "a course aimed at seniors and beginning graduate students in physics and astronomy at Cornell. This course defined the level at which the book is written." One can only say that any student who masters this book and works all the test questions supplied (with answers) must be regarded as pretty darned well educated in the theoretical physics and the mathematical apparatus needed in modern astrophysics.

This is indeed a theoretician's book, and much of what is contained in it can be found in one form or another in other texts or research papers. Harwit has made a prodigious effort in organizing all this information between two covers in a logical sequence.

Chapters two through twelve cover the gamut of astrophysical processes from the distances of astronomical objects through gravitational dynamics, thermodynamics, radiation theory, quantum processes, properties of stars, the interstellar medium, and cosmology. There is also a rather short, rather philosophical, and speculative chapter on — what else? — life in the universe.

Harwit's text shows no indication of the agonizing twists and turns that have gone into the determination of the best values of some of the observational parameters. For example, the value of the Hubble constant is flatly taken to be 75 kilometers per second per megaparsec, which is unlikely to satisfy the proponents of the two discordant values this figure is the mean of. The discussion of the cluster parallax method is presented as the determination of the time rate of variation of the cluster diameter, which is a mathematician's way of looking at it, not what has actually been done.

In the discussion of Olber's paradox there is a reference to mutual shadowing of stars, though the application of the unit sphere theorem would still result, not only in the sky being bright, but in us all being fried by the stellar radiation. Nor is there any indication of the real properties of determining extinction and reddening encountered in stellar photometry.

These are perhaps minor quibbles that should not detract from the masterly mathematical exposition of such a galaxy of astrophysical processes. One might wonder what impression the students are left with. This reviewer recalls listening to the late Sir Arthur Eddington, who half a century ago gave what seemed so complete an account of stellar structure that there seemed to be no problems left to solve. Harwit in his turn achieves so remarkable a degree of completeness that perhaps the modern student will be left with a similar impression. — *David S. Evans, University of Texas*

### *THE MEN WHO WENT TO THE MOON*

*For All Mankind* by Harry Hurt III, (Atlantic Monthly Press, A Morgan Entrekin Book, 1988), ISBN 0-87113-170-6, hardcover, 348 pages, $22.95.

You are there as all twenty-four *Apollo* astronauts squirm into their space suits; as eleven giant Saturn 5 rockets slowly clear the launch tower; as twelve men walk, explore, and pose on the Moon; and as all twenty-four astronauts struggle with life after *Apollo*.

Harry Hurt's account of the *Apollo* missions to the Moon is rich in detail. Every major event of the nine-year program as well as each minor flight maneuver is chronicled. Using press accounts, transcripts, autobiographies, and interviews, Hurt reveals both the technical components and the personalities that made the missions work.

The human element can be found throughout the book among the background of rocket burns, space food, and other technical aspects of the mission. The astronauts do not appear as full-blooded characters in this drama until the closing chapters of the book, when their post-*Apollo* lives are examined. Hurt resists portraying these men as technoheroes by showing that they have the same marital stress, financial concerns, and flatulence as the rest of the world.

*For All Mankind* does not have the dramatic storytelling of Tom Wolfe's *The Right Stuff* or the introspective reflections of an astronaut autobiography. It is, however, a very thorough retelling of an

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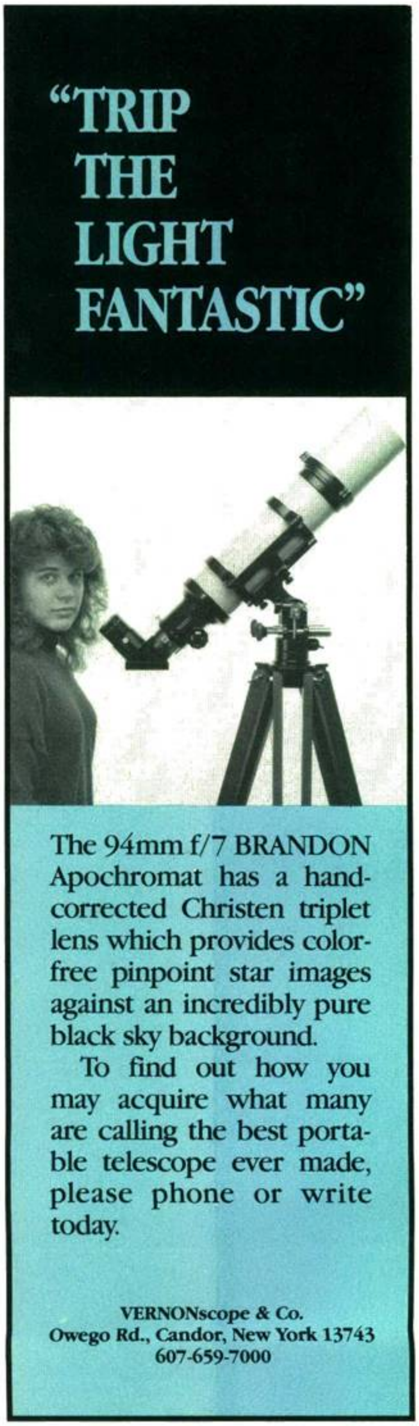

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amazing accomplishment that, fourteen years after the last *Apollo* flight, is too easily forgotten. — *Stephen Cole*

## ASTRONOMY FORCED INTO NEW AGE MOLD

*The Night Sky: The Science and Anthropology of the Stars and Planets* by Richard Grossinger, (Jeremy P. Tarcher, Inc.), ISBN 0-87477-489-6, paperback, 480 pages, $11.95.

Be forwarned. This revised edition of Grossinger's earlier work, published in 1981 under the same title, is not a book about the science of astronomy. It is a book about the New Age social implications of astronomy, astrophysics, astrology, and the mystical astrum. Grossinger does not try to reconcile these subjects; instead, he gives them equal importance. But the hybrid doesn't necessarily work for the astronomy enthusiast. If you're looking for a book that speaks to that inner stirring you experience when you stand beneath a starry sky, you may want to keep looking.

Grossinger begins the first two chapters of this work by painting the reader into a morass pervaded by darkness and futility reminiscent of Carlos Casteneda. With all candor, had I not been reviewing the book, I might have used it as kindling for the fireplace at the end of these chapters.

In the third chapter the author begins to relate the history of Western astronomy and develops this topic through the first half of the volume. But he portrays the story of astronomical history in a light seldom seen by the modern day astronomer —not in the focused clinical light of scientific examination but in the dim lantern light of the searcher in the night.

Through the next several chapters he walks us through the worlds of astrology, both ancient and modern, and astrology's relationship to today's astronomy and astrophysics. He examines the many types of astrology, of which there are far more than the average person realizes. He moves on to consider UFO phenomena and the ramifications of extraterrestrial encounters, abductions, and guidance through our evolution. In one chapter he even examines the pop-star cults of the 1950s and 1960s and the waves they set undulating into the New Age.

As intriguing as the title sounds, this book is definitely not a work of physical science. However, the title and tag line of this volume do not forewarn the potential buyer of the book's true content. Mystical vision quests, astral travels, and astromancy are the significant topics throughout the book. Perhaps they *should* be in a book on the anthropology and epistemology of the stars and planets and their occult pulse throughout the history of mankind, but they have no place in a science book.

The provocative concepts and insights in this volume are mired in the New Age bog. Moreover, I found Grossinger's writing style tedious and cumbersome, many times without apparent point. The reader who enjoys the arcane and esoteric may find enjoyment here, but those seeking to understand science will not. — *Richard Stanton*

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*Astrology: True or False? A Scientific Evaluation* by Roger B. Culver and Philip A. Ianna, (Prometheus Books, 1988), ISBN 0-87975-483-4, paperback, 228 pages, $13.95.

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*Radio Astronomy*, second edition, by John D. Kraus, (Cygnus-Quasar Books, P.O. Box 85, Powell, OH 43065, 1986), paperback.

## REFERENCE

*The American Heritage Dictionary of Science* by Robert K. Barnhart, (Houghton Mifflin, 1988), ISBN 0-395-48367-0, hardcover, 740 pages, $19.95.

*Annual Review of Astronomy and Astrophysics*, volume 26, edited by Geoffrey Burbidge, David Layzer, and John G. Phillips, (Annual Reviews, Inc., 1988), ISBN 0-8243-0926-X, hardcover, 703 pages, no price given.

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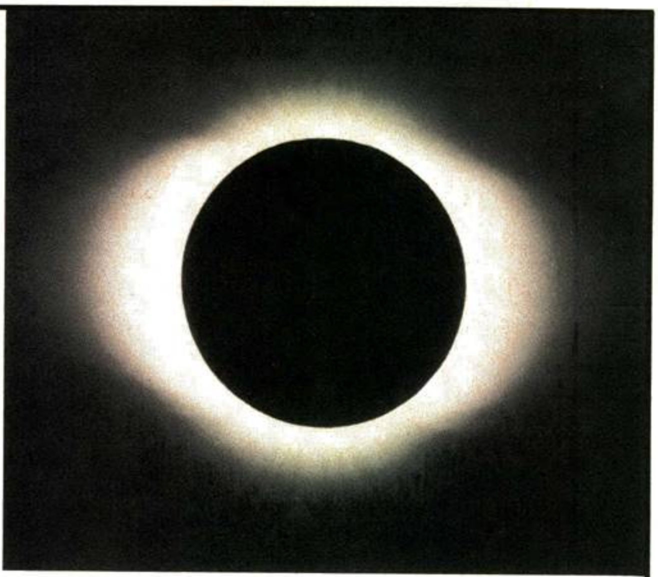

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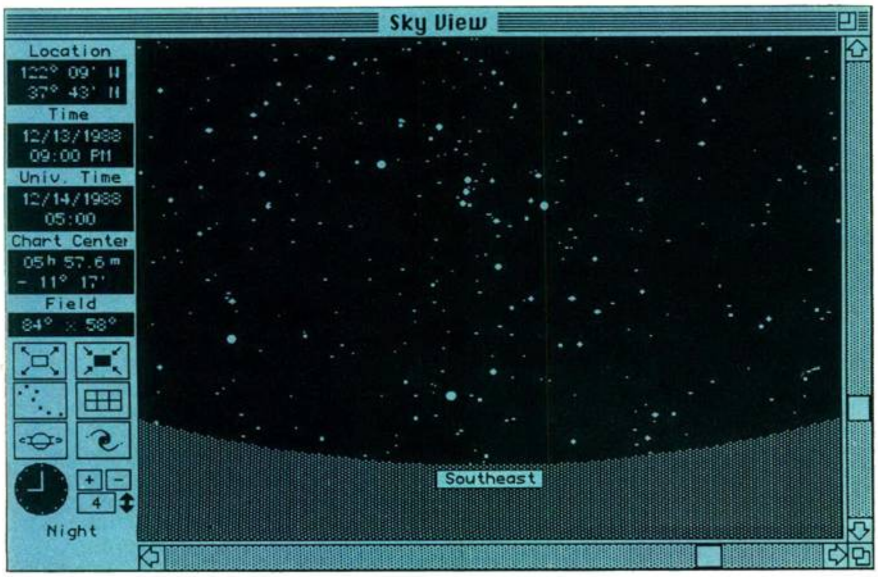
The Celestial Sphere option shows a single hemisphere of the sky all at once as a perspective view of the celestial sphere seen in three dimensions. Local View gives an Earth-based sky you can orient in any direction and customize to any time, date, or location on Earth. You can make this sky update in real time so it will mimic the real sky outdoors — or you can choose rates either faster or slower and you can go forward or backward in time.

The Star Atlas view covers an initial area of 90° by 60° with six zoom-in magnification levels, the tightest of which gives a field of 2° by 1°. You can easily select a portion of a field to enlarge by putting the cursor at any point, holding the mouse button down, and dragging diagonally to enclose your field. Release and *Voyager* zooms in on that area.

Each of these options provides scrolling features with numerical read-outs in right ascension and declination. You can also center the field on any constellation or right ascension and declination you choose and see the view from any point on Earth.

The other part of the display, the panel, stands on the left and contains information boxes that show the latitude and longitude of your observing location, local time, universal time, the coordinates of the chart center, and the size of the field of view. Below these boxes six buttons toggle on and off to enlarge and reduce the display and insert constellation outlines, a coordinate grid, solar system objects, and deep-sky objects.

I found that calling up all the deep-sky objects in the database was a mistake when I was looking at a large field of view. The field becomes too crowded and confusing — this option works better when you are dealing with a small area of sky. You can also choose stars and deep-sky objects by magnitude, and, again, it's a matter of how much is enough for your needs. Besides the galaxies and nebulae, there are plenty of double and variable stars for aficionados to work with.



Location
122° 09' W
37° 43' N
Time
12/13/1988
09:00 PM
Univ. Time
12/14/1988
05:00
Chart Center
05h 57.6m
- 11° 17'
Field
84° × 58°

**ORION IS RISING** in the southeast, as shown by *Voyager*'s Local View mode.

*Voyager* seems to do almost everything and do it extremely well. Listing all the capabilities of this program is impossible in the space here, so rather than describe everything, I will give an abridged version of the pull-down menu.

FILE lets you load and save your favorite astronomical events plus re-create or preset events and print the screen to an ImageWriter or LaserWriter. CONTROL selects the view, time, location, magnitude limits, sky rotation, deep-sky objects, precession, and sky legend.

FIELD centers the display on a given constellation, position, or object, or returns you to the last field. It will find and center objects by name, plus find the Sun, Moon, or Earth if you are observing from another point in the solar system. DISPLAY lets you turn on Messier objects, binary and variable stars, Jupiter's moons, the zodiac, ecliptic, horizon, meridian, galactic equator, constellation names, a white sky with black stars, and a fine-net coordinate grid.

OPTIONS provides some powerful routines. The Observe from Another Planet option does just that and also lets you observe from any point in space up to one hundred astronomical units from the Sun (astronomical artists take note). Track Planets steps planets along through the sky at specified time intervals and lets them leave a trail. Define New Orbit will track any object you provide the orbital elements for. Planet Positions gives tabular data on positions while orbital data includes all the orbital elements. Orrery displays the solar system from a point above the Sun's pole. Sky Plot graphs a display of objects of your choice. Angular Separation displays the separation between the last two objects selected. Ecliptic Coordinates and Galactic Coordinates can be displayed for any selected object. Whew!

The eighty-six-page manual is well written and easy to use. All in all, I found *Voyager* is a superb, user-friendly program for the amateur astronomer, whether armchair or active observer. The graphics are clean and reproduce well. The speed of the program makes it a pleasure to work with. — *Bruce Bond*

## *OBSERVING ACCESSORIES*

**Copernicus Binoc-U-Mount**, (Innovative Energies, 50 Tower Road, Newton, MA 02164), $45.

Skywatching with binoculars is a lot more fun if the field of view isn't jump-

**COPERNICUS BINOC-U-MOUNT** is intended to mate large and astronomical-size binoculars to a photo tripod.

ing around. While most people can hand-hold binoculars of about 10x or less, you always see more at any power if the instrument is held rock steady. For binoculars that don't have a built-in tripod socket, the Copernicus is a "saddle" intended to hold a pair of binoculars on a photo tripod for steady viewing.

The saddle is stitched, full-grain leather and finished very nicely in shiny black. There is a ¼-20 tripod socket in the middle of the bottom piece, which is stiffened with a thin metal plate. The inside of the bottom piece has a compressible pad to cushion the binoculars. The sides bend up and two Velcro-tipped stretch straps reach across from one side to the other and hold the binoculars in the saddle.

The information provided by the company indicated the Copernicus model is intended for "larger and astronomical size" binoculars, so I tried it with my 7x50s, which have the common Porro-prism ("dogleg") design. However the 7x50s were not large enough for the saddle to grab them firmly, and no amount of fiddling with the straps gave a good fit. I next tried a pair of 11x80s, but again the fit was too loose. In both cases I did not feel comfortable entrusting the instrument to the saddle unless the binoculars were aimed at the horizon. Based on this, I would rate the Copernicus as completely unsuitable for astronomical use.

I think the key is getting a very close match between the size of the binoculars and the saddle. (The company makes two other models: the Compact, at $35, is for mini-binoculars and the Silhouette at $39 is for standard sizes.) You could use the saddle without a tight fit, provided you were willing to keep one hand always on the instrument to prevent it falling. Binocular users who never tip their instruments very far from the horizontal — birders at a pond watching from a blind — might find a loose fit less of a problem. — *Robert Burnham* ☐

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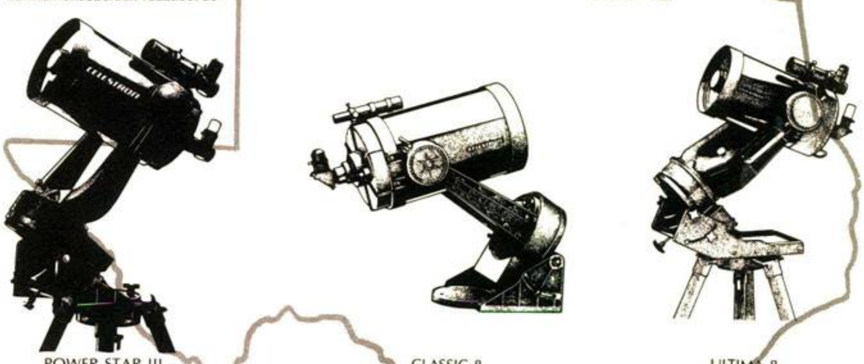

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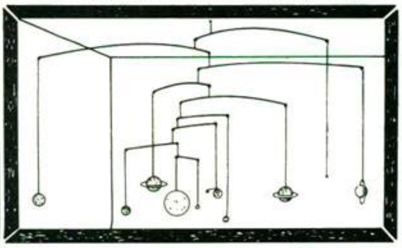

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# Meetings and Events

**February 25**
**Astrophoto VIII,** California State University at Fullerton. Seminar and photo exhibit co-sponsored by the Orange County Astronomers and the Ventura County Astronomical Society. Contact: John Sanford, 2215 Martha Avenue, Orange, CA 92667. Phone: (714) 639-8446.

**March 4**
**Astronomy Day,** Museum of History and Science, Louisville, Kentucky. Sponsored by the Louisville Astronomical Society. Contact: Ingrid Siegert-Tange, 1825 Windsor Place, Louisville, KY 40204. Phone: (502) 459-6689.

**March 9-12**
**Third New Zealand Photo-Electric Conference,** Blenheim, New Zealand. Contact: Stan Walker, Auckland Observatory, P.O. Box 37 735, Auckland, New Zealand. Phone: 64 (9) 548-736.

**March 18**
**New England Astro-Fest #2,** Farmington, Connecticut. Commercial astronomy equipment exhibition, sponsored by New England Astro-Optics, Inc. Contact: New England Astro-Optics, Inc., Attention: Astro-Fest #2, P.O. Box 834, Simsbury, CT 06070.

**April 28-30**
**3rd Annual Southern Star Conference,** Wildacres retreat in the Blue Ridge Mountains of North Carolina. Hosted by the Charlotte Amateur Astronomers. Contact: Heather Fisk, P.O. Box 220234, Charlotte, NC 28222. Phone: (704) 332-4670.

**April 29**
**43rd Annual Convention of the North Central Region of the Astronomical League,** Rockford, Illinois. Hosted by the Rockford Amateur Astronomers, Inc. Contact: Carol Beaman, 6804 Alvina Road, Rockford, IL 61103. Phone: (815) 962-6540.

**May 13**
**16th Annual Astronomy Day.** Contact: Gary E. Tomlinson, Astronomy Day Coordinator, Astronomical League, Chaffee Planetarium, 54 Jefferson Avenue SE, Grand Rapids, MI 49503. Phone: (616) 456-3985.

**Astronomy Day Celebration,** Hoffman Estates, Illinois. Sponsored by the Northwest Suburban Astronomers. Contact: Bob Long, 4960 Chambers Drive, Barrington, IL 60010. Phone: (312) 991-7432.

**May 19-21**
**Royal Astronomical Society of New Zealand Conference,** Invercargill, New Zealand. Sponsored by the Southland Astronomical Society, Inc. Contact: Darryl Jones, Southland Museum and Art Gallery, P.O. Box 1012, Invercargill, New Zealand.

**May 26-29**
**Riverside Telescope Makers Conference,** Camp Oakes, Big Bear, California. Contact: Cliff Holmes, 8642 Wells Avenue, Riverside, CA 92503. Phone: (714) 689-6893.

**May 29-June 4**
**Texas Star Party,** Prude Ranch, Fort Davis, Texas. Contact: T.S.P. Registrar, Bobby Braley, Department "A," P.O. Box 386, Wylie, TX 75098.

*Please submit announcements at least four months before the date of the meeting or event.*

*When you write to organizations listed in Meetings and Events, include a self-addressed, legal-size envelope with your request for information.* ☐

## READER EXCHANGE

WANTED – Comments from those who have used Sky Scientific Astrocamera model CL. Especially in comparison with 35mm cameras and films. Contact Robert A. Midiri, 205 Horseshoe Lane, Coatesville, PA 19320. Phone (215) 383-4547.

WANTED – Photos, slides, and technical articles about Sirius. Contact Bassel A. Reyahi, P.O. Box 86, Tulkarm, West Bank, Israel.

WANTED – Donations of ASTRONOMY and *The Planetary Report* with coverage of the *Voyager 2* encounter with Uranus in 1986. Any photographic reproductions also welcome. Contact Ryan Sicilia, W1117 Keirnan Avenue, Spokane, WA 99205.

WANTED – Halley's Comet memorabilia and collectibles. Send description of items for a cash offer. Contact Doug Smith, 385 Allison Road, Murfreesboro, TN 37130.

WANTED – Tripod and wedge for a Celestron C8 telescope. Contact Donald Covault, 2000 La Vista Circle, Tucker, GA 30084. Phone (404) 939-3149.

WANTED – Sixteen-year-old male would like to correspond with other amateur astronomers, preferably in the United States. All letters will be promptly answered. Contact Joga Bains, 77 Boundary Road, Chatham, Kent, England, ME4 6UG.

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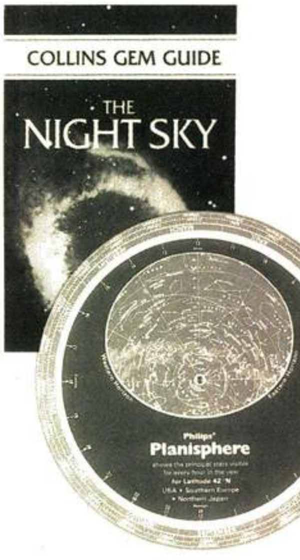

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# Readings and Resources

**Looking inside the Sun** (page 20)
*Our Turbulent Sun* by Kendrick Frazier, (Prentice-Hall, 1982). A good outline of what is known about the Sun plus a look at the problems with current models.

**New Window on Star Birth** (page 32)
"Radio Astronomy Looks to Space" by Kurt W. Weiler, Brian K. Dennison, and Kenneth J. Johnston, ASTRONOMY, May 1988. Observing millimeter and submillimeter wavelengths from Earth and prospects for space-based observatories.

**Cosmic Jets** (page 40)
"Anatomy of a Cosmic Jet" by Jeff Kanipe, ASTRONOMY, July 1988. Detailed speculations about the nature and structure of the M87 jet as well as the latest on the computer modeling of jets.

**Eight Lunar Wonders** (page 66)
Association of Lunar and Planetary Observers, c/o Harry Jamieson, P.O. Box 143, Heber Springs, AR 72543.
*Exploring the Moon through Binoculars and Small Telescopes* by Ernest Cherrington, (Dover, 1984). The best telescopic guide to the Moon in print.

**Piece of the Solar System** (page 73)
*How to Build Realistic Model Railroad Scenery* by Dave Frary and *Scenery for Model Railroads* by Bill McClanahan, (both published by Kalmbach Publishing Co.). Some of these techniques apply to making models of other worlds.

**Galaxy Hunting** (page 78)
*The Color Atlas of Galaxies* by James D. Wray, (Cambridge University Press, 1988). Color photographs and basic data for more than six hundred bright galaxies.

**Daytime Planetary Observing** (page 86)
*The Astronomical Almanac*, (Department of the Navy, Washington, and Her Majesty's Stationery Office, London). To order the 1989 edition, send $24 to the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402.

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## CREDITS

*Cover*: Lick Observatory; *page 4*: NRAO/Associated Universities, Inc.; *page 10*: D. A. Godfrey, NOAO; *page 14*: J. W. Christy, U.S. Naval Observatory; *page 16*: NASA; *page 18*: Dave and Marion Bachtell; *pages 20-21, 23, and 24-25*: paintings by Paul DiMare; *page 26*: National Solar Observatory; *pages 28-29*: National Solar Observatory, diagram by Thomas L. Hunt; *page 32*: California Institute of Technology; *page 33*: painting by Zaqueline Souras; *page 34, left*: John Gleason (8-inch f/1.5 Schmidt camera, Tech Pan 2415 film, 45-minute exposure), *right*: *IRAS* image; *page 36*: map obtained at the Caltech Submillimeter Observatory, courtesy of Edmund C. Sutton, University of California at Berkeley; *pages 40-41*: NRAO/Associated Universities, Inc.; *pages 47-50*: x-ray, ultraviolet, and visible light images courtesy of *Solar Max*/NASA, hydrogen-alpha image courtesy of Solar Observing Optical Network, U.S. Air Force, magnetic field image courtesy of National Solar Observatory, radio image courtesy of NRAO; *page 58*: map courtesy of Fred Espenak; *page 63*: Diego Meozzi (5-inch f/10 SCT, Ektachrome 64 Professional film, 1/1,000-second exposure); *page 66*: Richard Wessling (12.5-inch Newtonian, Plus-X film with 23A filter, 5-second exposure); *page 67*: John E. Westfall (10-inch Cassegrain, Tech Pan film, 1/2-second exposure at f/45); *page 68, top*: Lick Observatory, *bottom*: Jean Dragesco (14-inch SCT, Tech Pan film); *page 69*: Tim Tomljanovich; *page 70*: John E. Westfall (10-inch Cassegrain), *top left*: (Fujichrome 100, 1/2-second exposure at f/24), *bottom right*: (Kodachrome 64 film, 1/2-second exposure at f/48); *pages 70-71 and 71, bottom*: Lick Observatory; *page 73*: Art Schmidt; *page 79*: Tony Hallas and Daphne Mount (14-inch f/7.2 SCT, hypered Tech Pan film, 60-minute exposure); *page 80, top*: Kim Zussman (11-inch f/10 SCT, hypered Tech Pan film, 50-minute exposure), *middle left*: Mace Hooley (8-inch f/1.5 Schmidt camera), *bottom right*: Kim Zussman (11-inch f/10 SCT, hypered Tech Pan film, 120-minute exposure); *page 81, top*: Kim Zussman (11-inch f/10 SCT, hypered Tech Pan film, 130-minute exposure), *middle pair*: Jack Newton (16-inch f/5 reflector, 14-minute exposure on left, on right Ektachrome 400 film, 15-minute exposure), *bottom*: Jack Marling (17.5-inch f/4.5 reflector, Fujichrome 400 film, 30-minute exposure); *page 82*: Martin C. Germano, *top*: (8-inch f/5 SCT, 103a-F film, 40-minute exposure), *middle*: (8-inch f/6 reflector, hypered Tech Pan film, 60-minute exposure); *page 83, top*: Paul Roques (16-inch f/4.5 reflector, hypered Tech Pan film, 60-minute exposure); *page 84, left*: Kim Zussman (11-inch f/10 SCT, hypered Tech Pan film, 120-minute exposure), *right*: K. A. Brownlee (16-inch f/5 reflector, 103a-O film, 5-minute exposure); *page 87*: Mark Payne-Gill (12-inch f/5.2 reflector, Fujichrome 100D film, 1/125-second exposure); *page 90, top left*: sketch by Ivor L. Clarke (4.5-inch reflector at 250x), August 10, 1988, *top right*: sketch by Robert Bunge (31-inch f/7 reflector at 225x, 340x, and 541x), August 21, 1988, *bottom*: sketch by David L. Graham (10-inch f/6.3 reflector at 398x), September 9, 1988; *page 91, left*: sketch by Robert Albertson (6-inch f/8 reflector at 277x with a #25A filter), August 10, 1988, *right*: sketch by James S. Mullin (8-inch f/10 SCT at 160x), September 23, 1988, left-hand sketch made at 11:13 p.m. EDT, right-hand sketch at 11:30 p.m.; *page 92*: Lynn R. Hammond (135mm f/2.8 lens, Konica 3200 film, 3-minute exposure); *page 93*: Tom Ritland (1,400mm f/22 lens, Ektachrome 400 film, 1/1,000-second exposure); *page 96*: illustration by Todd Graveline.

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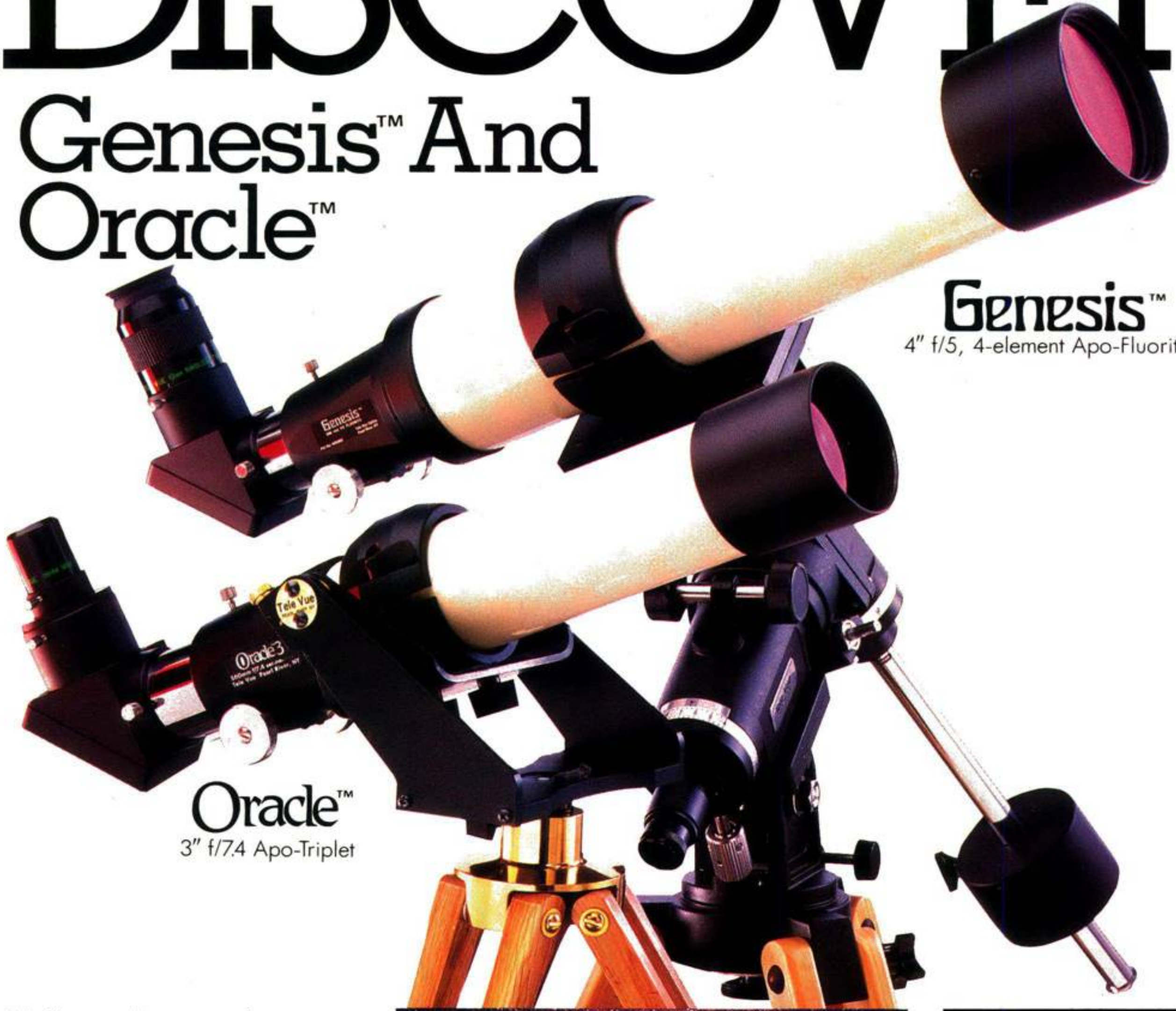

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